US009351754B2

(12) **United States Patent**
**Vakharia et al.**

(10) **Patent No.: US 9,351,754 B2**
(45) **Date of Patent: May 31, 2016**

(54) **ULTRASONIC SURGICAL INSTRUMENTS WITH DISTALLY POSITIONED JAW ASSEMBLIES**

(75) Inventors: **Omar J. Vakharia**, Cincinnati, OH (US); **Jeffrey D. Messerly**, Cincinnati, OH (US); **David Stefanchik**, Morrow, OH (US); **Steven P. Smolik**, West Chester, OH (US)

(73) Assignee: **Ethicon Endo-Surgery, LLC**, Guaynabo, PR (US)

( * ) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 393 days.

(21) Appl. No.: **13/538,711**

(22) Filed: **Jun. 29, 2012**

(65) **Prior Publication Data**

US 2014/0005704 A1 Jan. 2, 2014

(51) **Int. Cl.**

| | |
|---|---|
| ***A61B 17/32*** | (2006.01) |
| ***A61B 19/00*** | (2006.01) |
| *A61B 18/14* | (2006.01) |
| *A61B 18/00* | (2006.01) |

(52) **U.S. Cl.**

CPC ..... ***A61B 17/320092*** (2013.01); ***A61B 19/2203*** (2013.01); *A61B 18/1445* (2013.01); *A61B 2018/00875* (2013.01); *A61B 2018/1452* (2013.01); *A61B 2019/2215* (2013.01); *A61B 2019/2234* (2013.01)

(58) **Field of Classification Search**

CPC ..... A61B 17/320092; A61B 18/1445; A61B 19/2203; A61B 2018/1452; A61B 2019/2215; A61B 2019/2234

USPC ..... 606/169, 205, 207, 208, 51, 52

See application file for complete search history.

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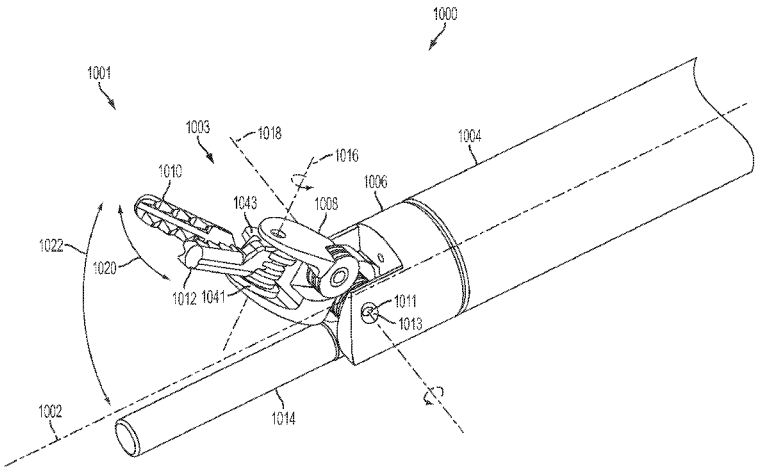
*Primary Examiner* — Corrine McDermott
*Assistant Examiner* — Sarah Simpson

(57) **ABSTRACT**

Various embodiments are directed to surgical instruments comprising an end effector, a shaft and a jaw assembly. The end effector may comprise an ultrasonic blade extending distally substantially parallel to a longitudinal axis. The shaft may extend proximally from the end effector along the longitudinal axis. The jaw assembly may comprise first and second jaw members. The jaw assembly may be pivotable about a first axis substantially perpendicular to the longitudinal axis from a first position where the first and second jaw members are substantially parallel to the ultrasonic blade to a second position. Additionally, the first and second jaw members may be pivotable about a second axis substantially perpendicular to the first axis.

**19 Claims, 50 Drawing Sheets**



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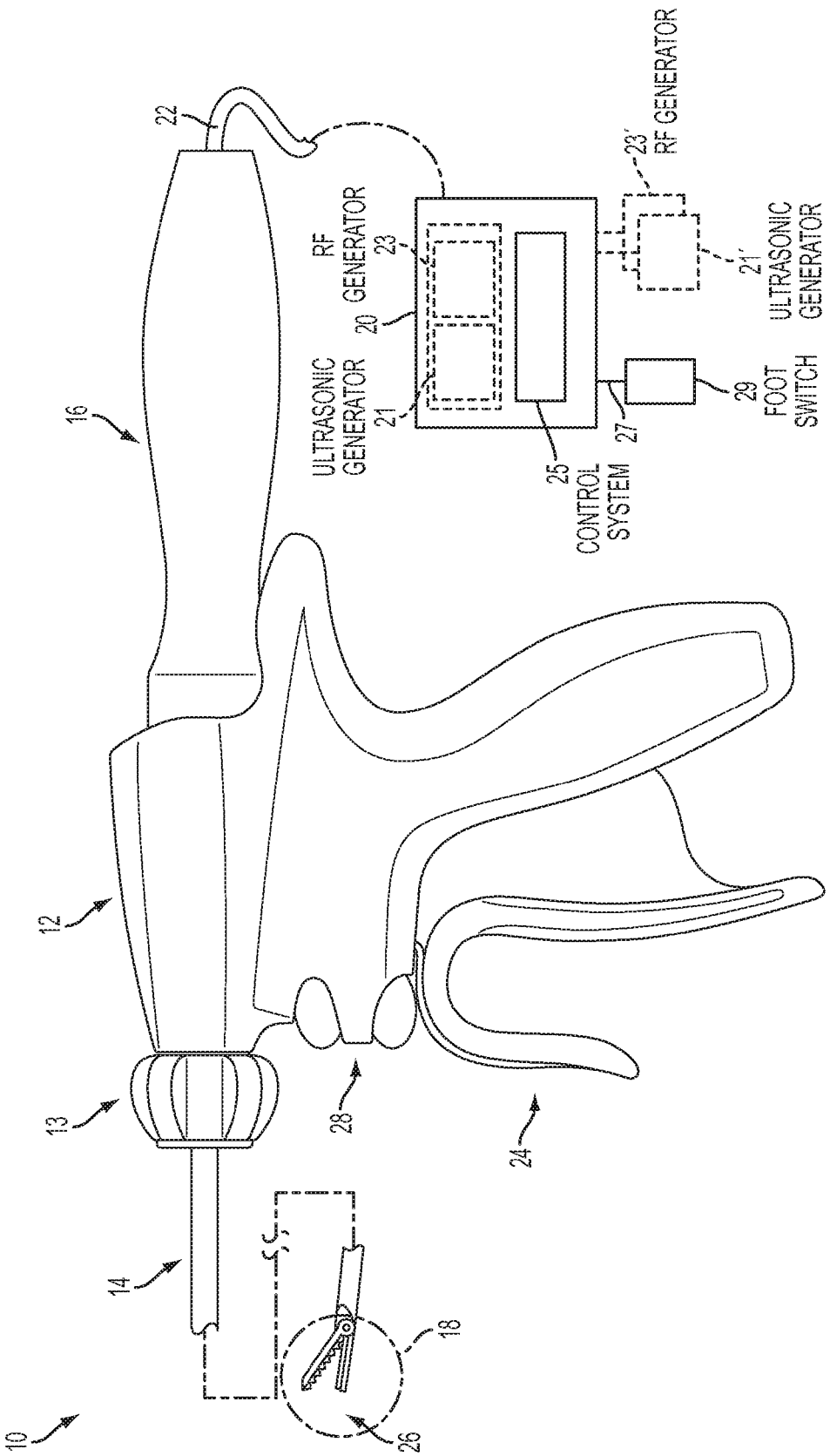
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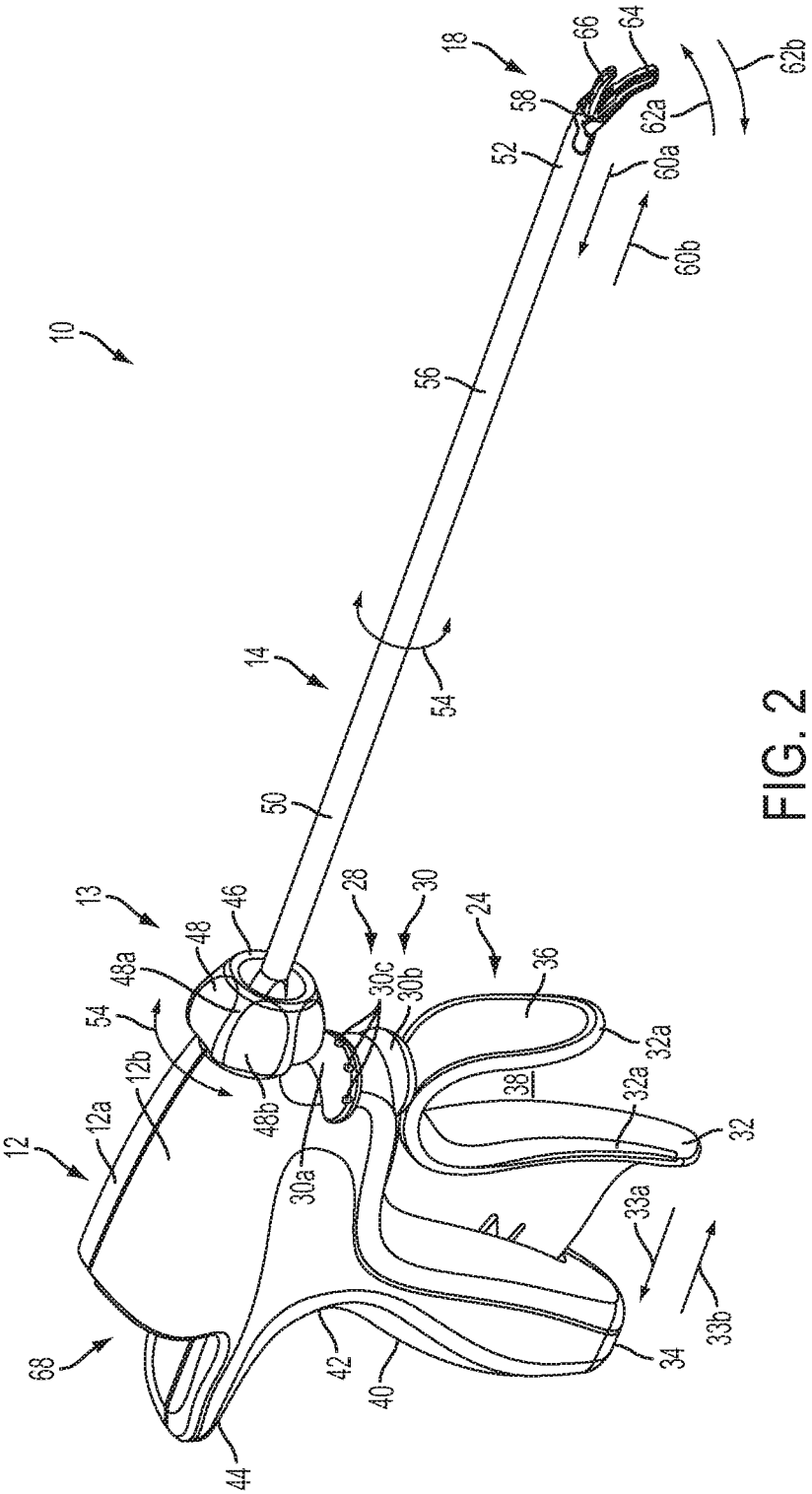
14
18
26
10

FIG. 1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12a
12b
13
14
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24
28
30
30a
30b
30c
32
32a
33a
33b
34
36
38
40
42
44
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48
48a
48b
50
52
54
56
58
60a
60b
62a
62b
64
66
68

FIG. 2

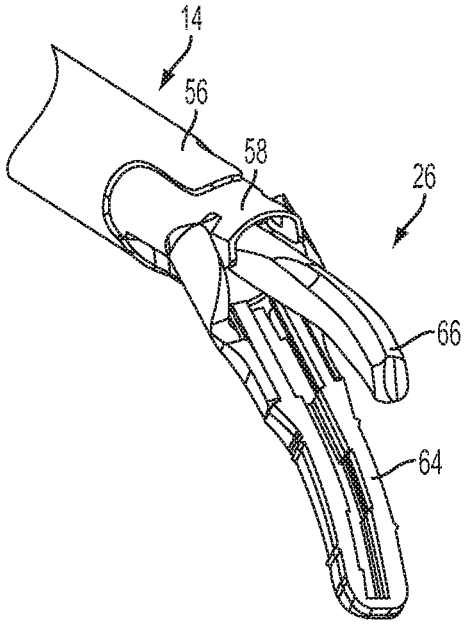



FIG. 3

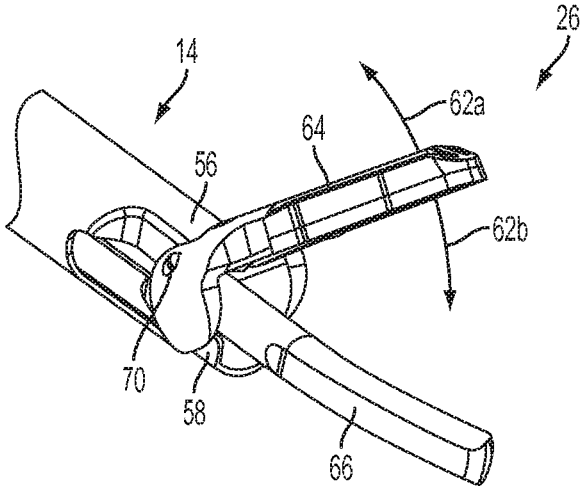
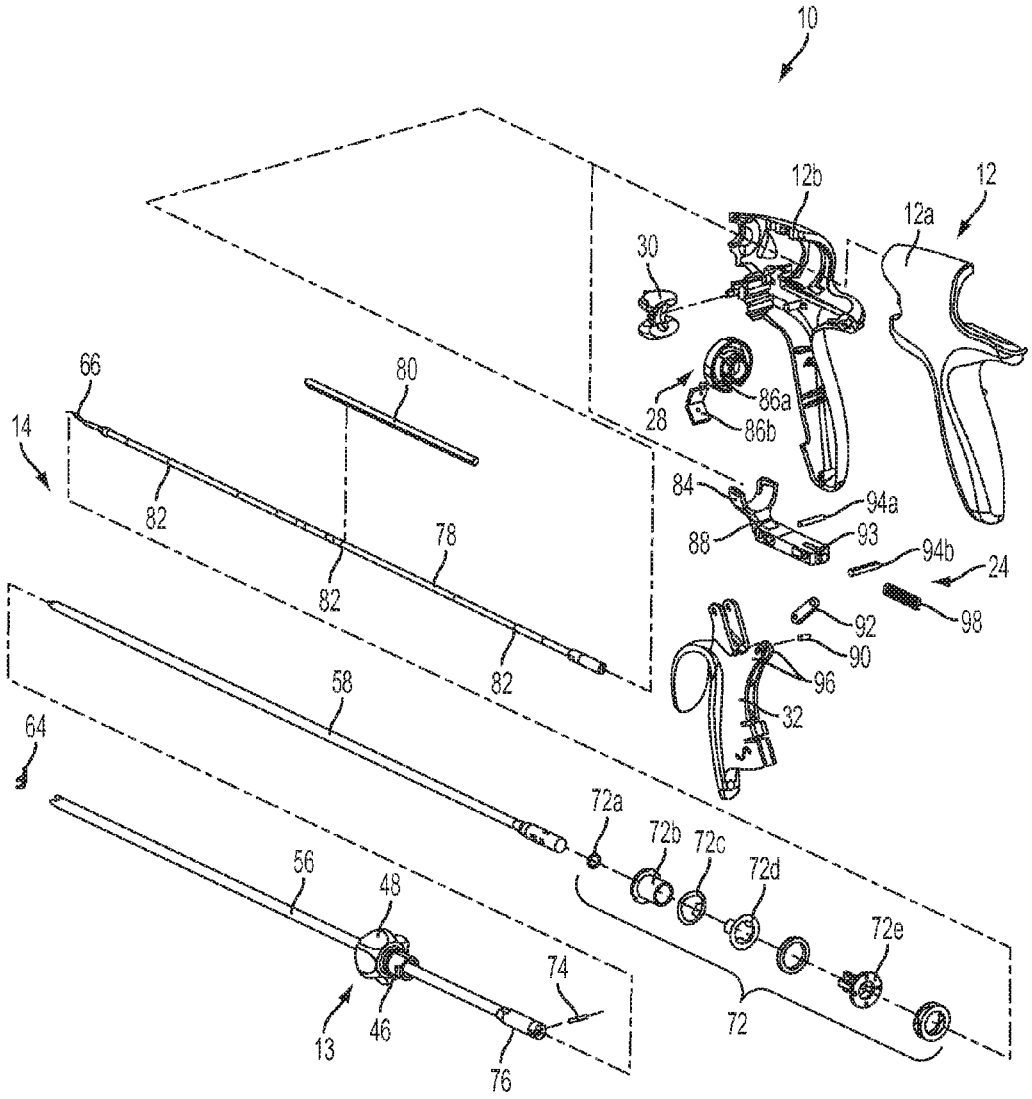



FIG. 4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12b
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12a
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66
80
14
28
86a
86b
82
84
94a
88
93
78
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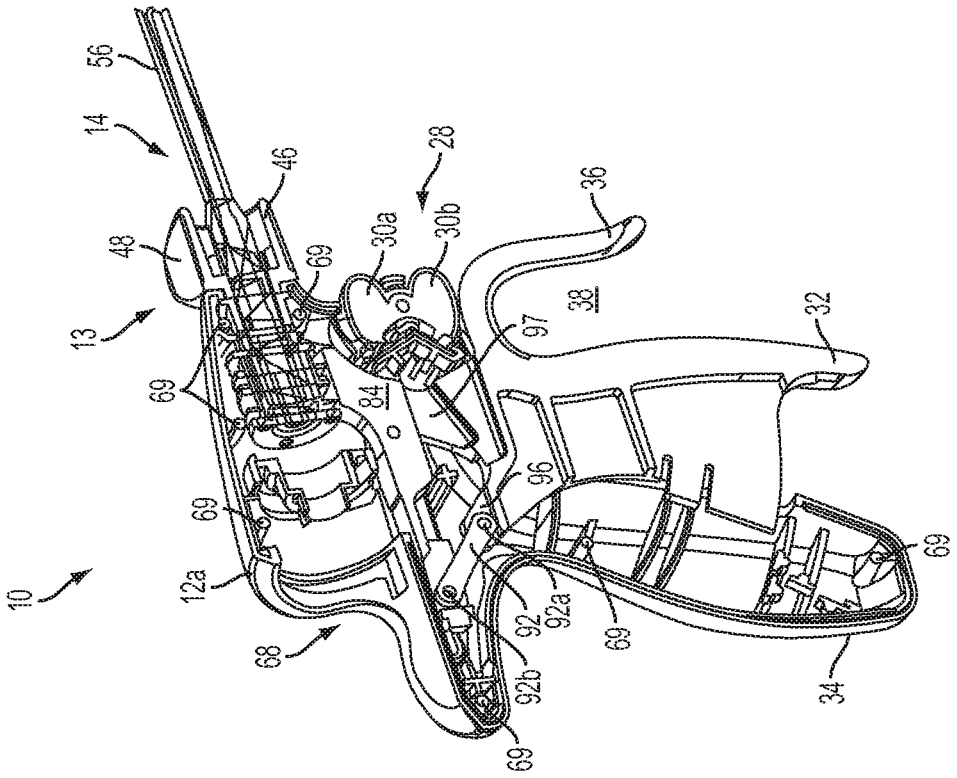
24
82
92
98
90
82
96
58
32
64
72a
72b
72c
72d
56
48
72e
74
13
46
72
76

FIG. 5


56
14
46
28
48
30a
30b
36
69
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13
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69
96
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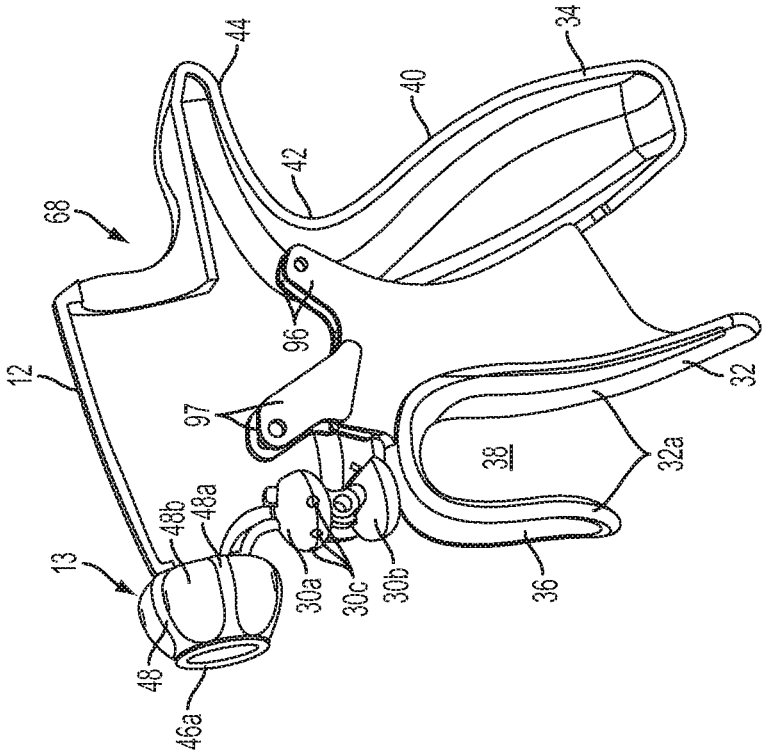
10
12a
92
92a
69
68
92b
34
69

FIG. 7


44
34
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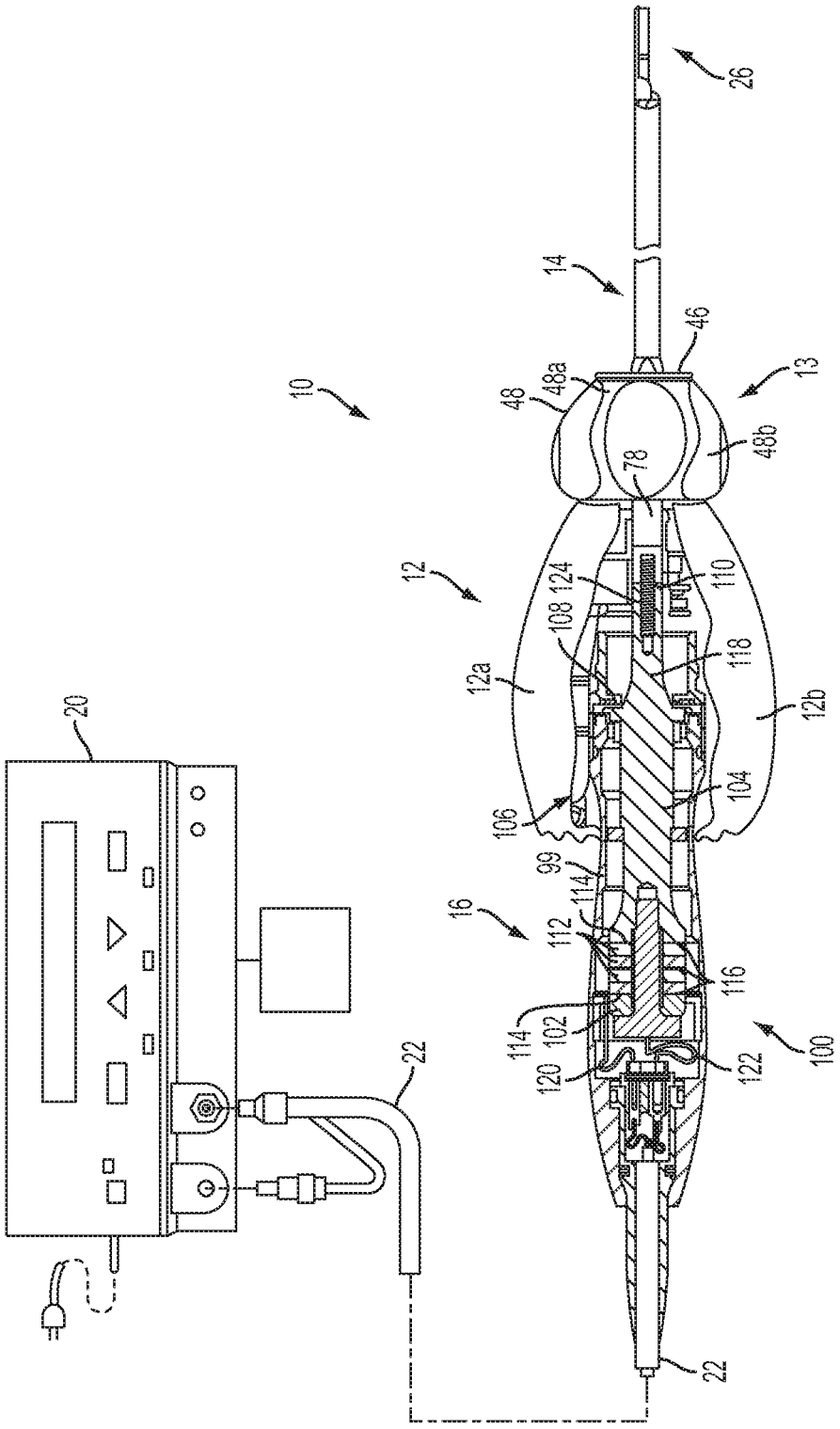
32a
48b
48a
13
30a
30c
30b
36
48
46a

FIG. 6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12b
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46
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48b
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112
114
114
116
118
120
122
124

FIG. 8

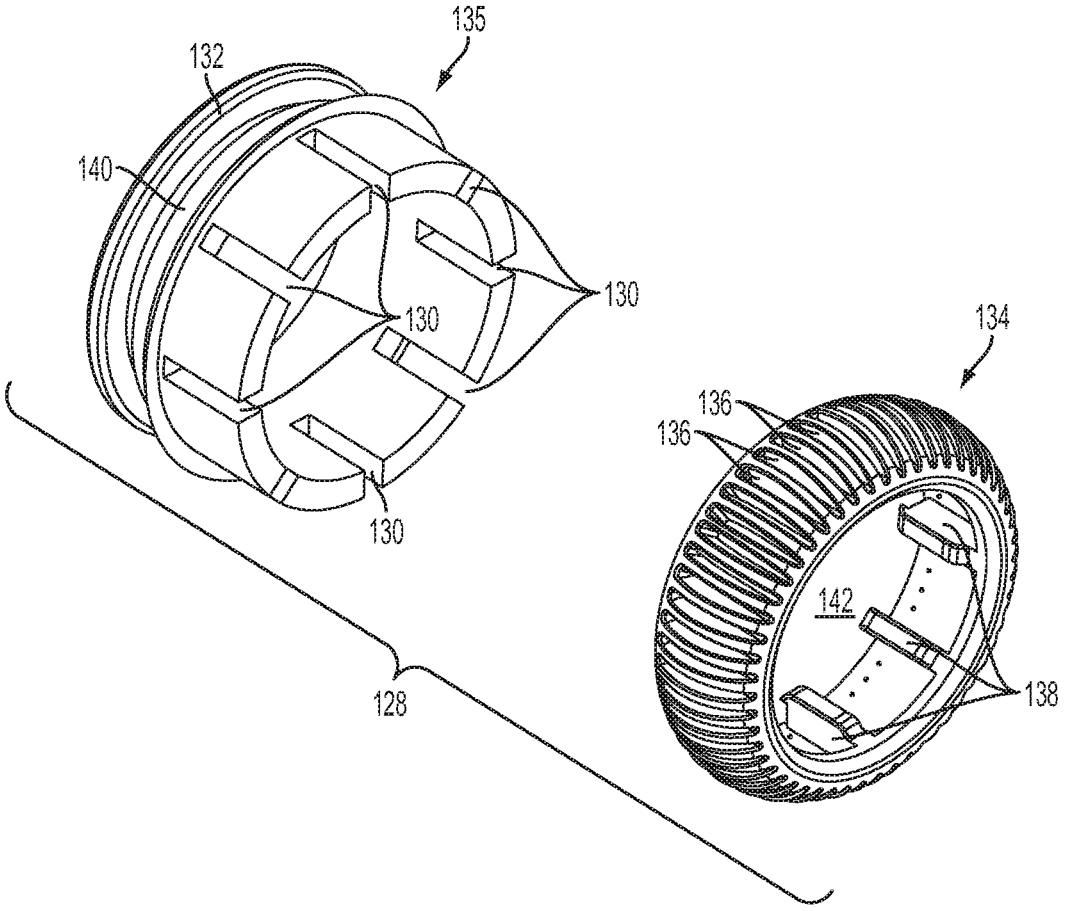



FIG. 9

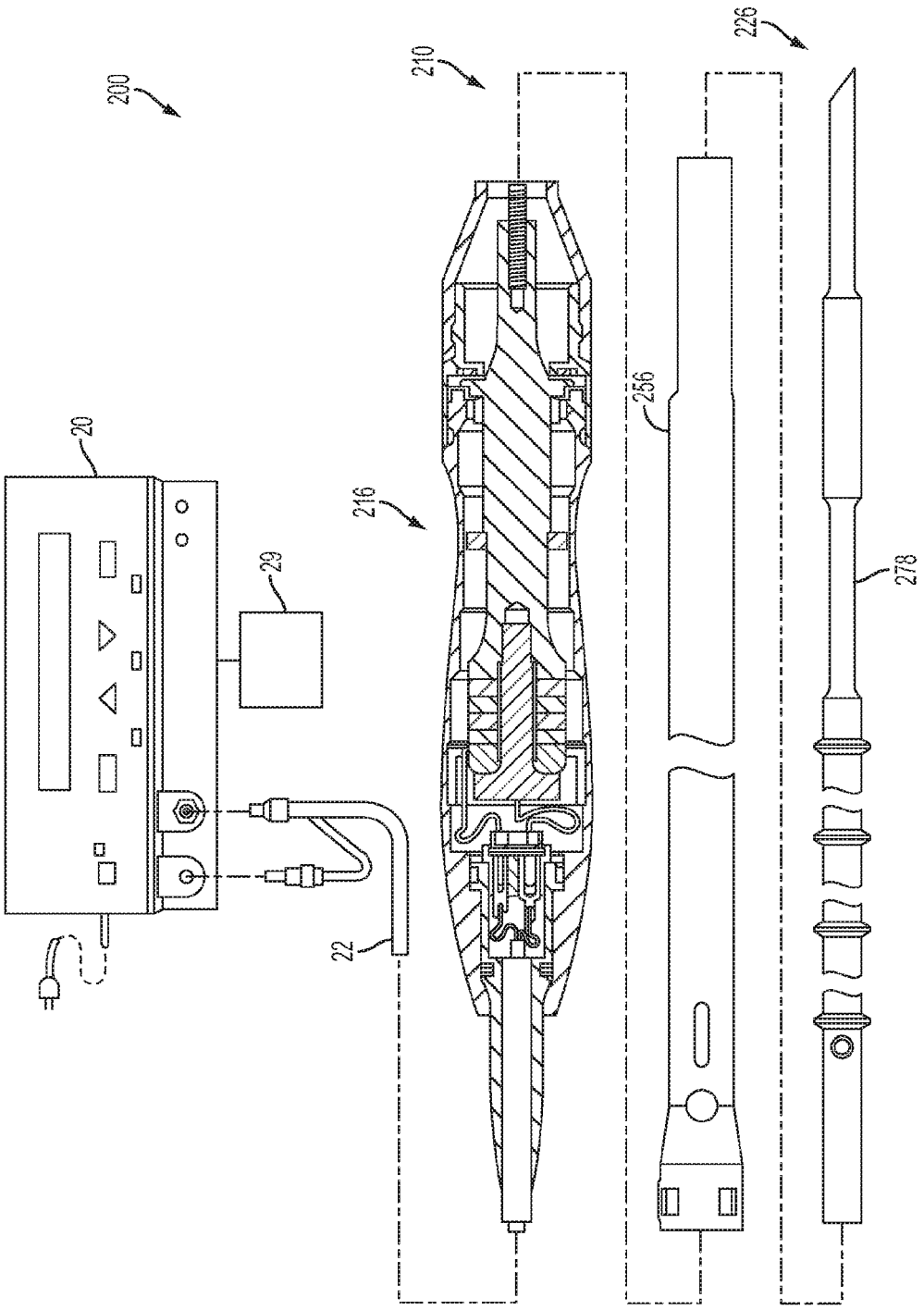
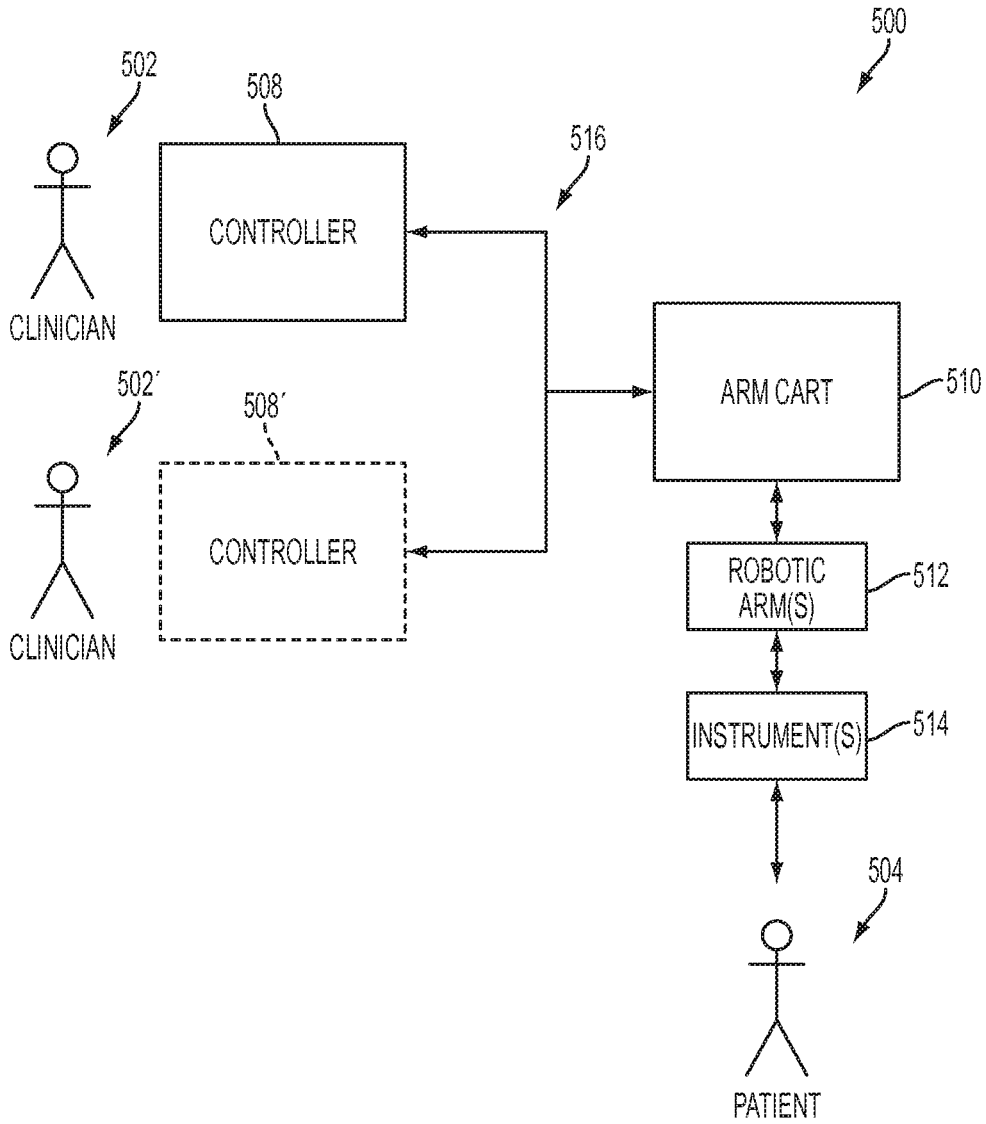



FIG. 10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502
508
516
CONTROLLER
CLINICIAN
ARM CART
510
502′
508′
CONTROLLER
CLINICIAN
ROBOTIC ARM(S)
512
INSTRUMENT(S)
514
504
PATIENT

FIG. 11

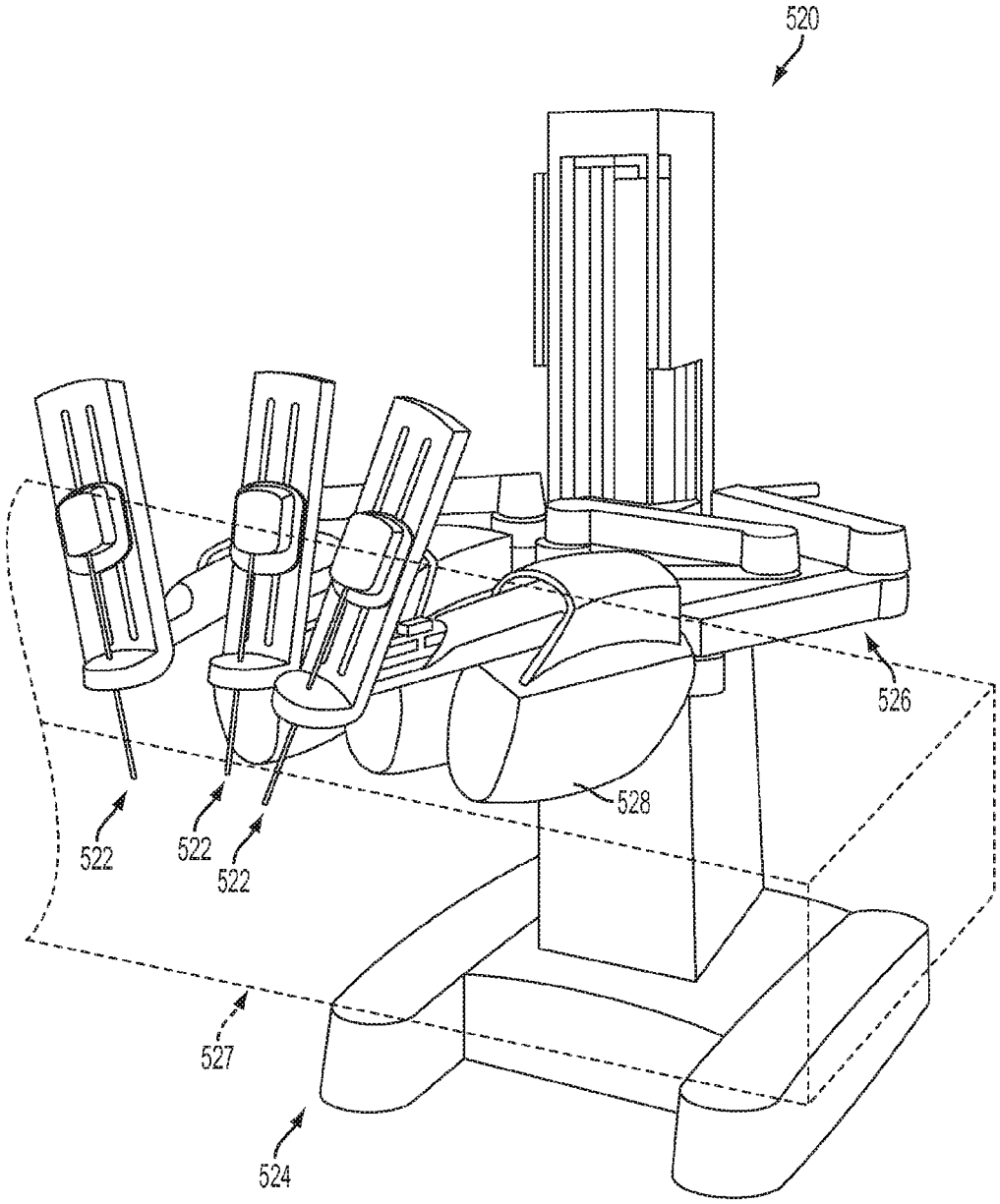
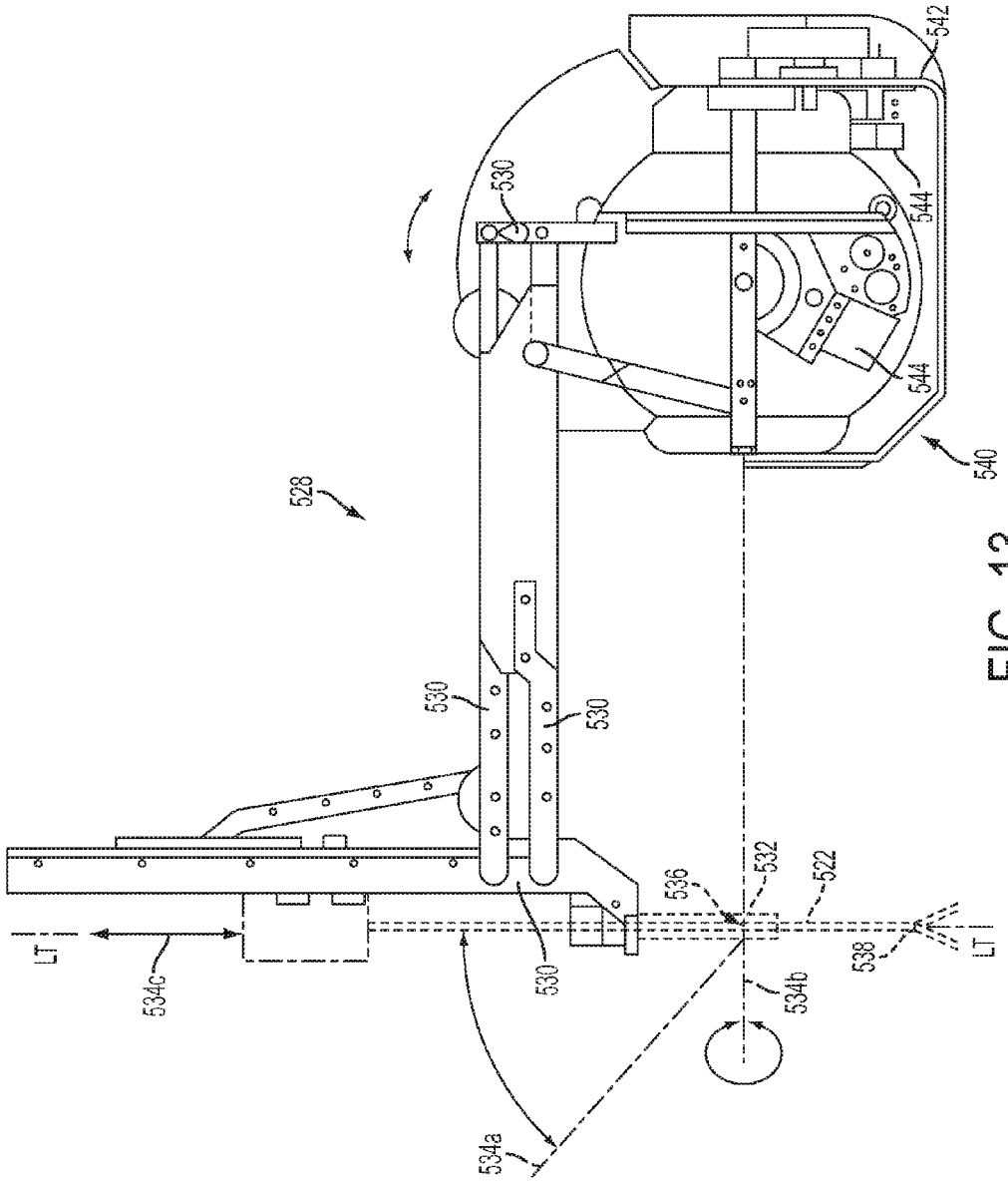



FIG. 12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530
530
536
532
522
LT
534c
530
538
LT
534b
534a

FIG. 13

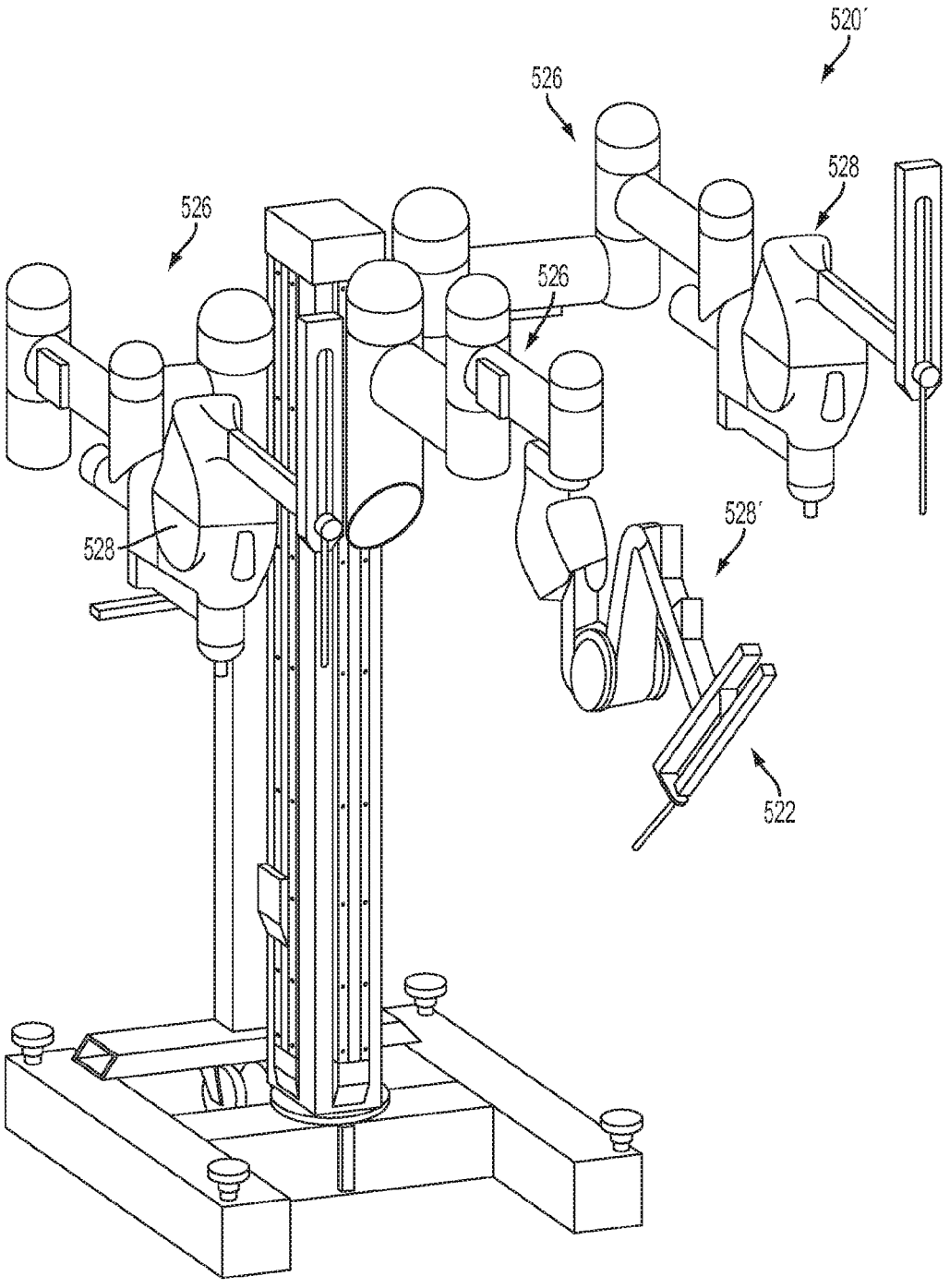



FIG. 14

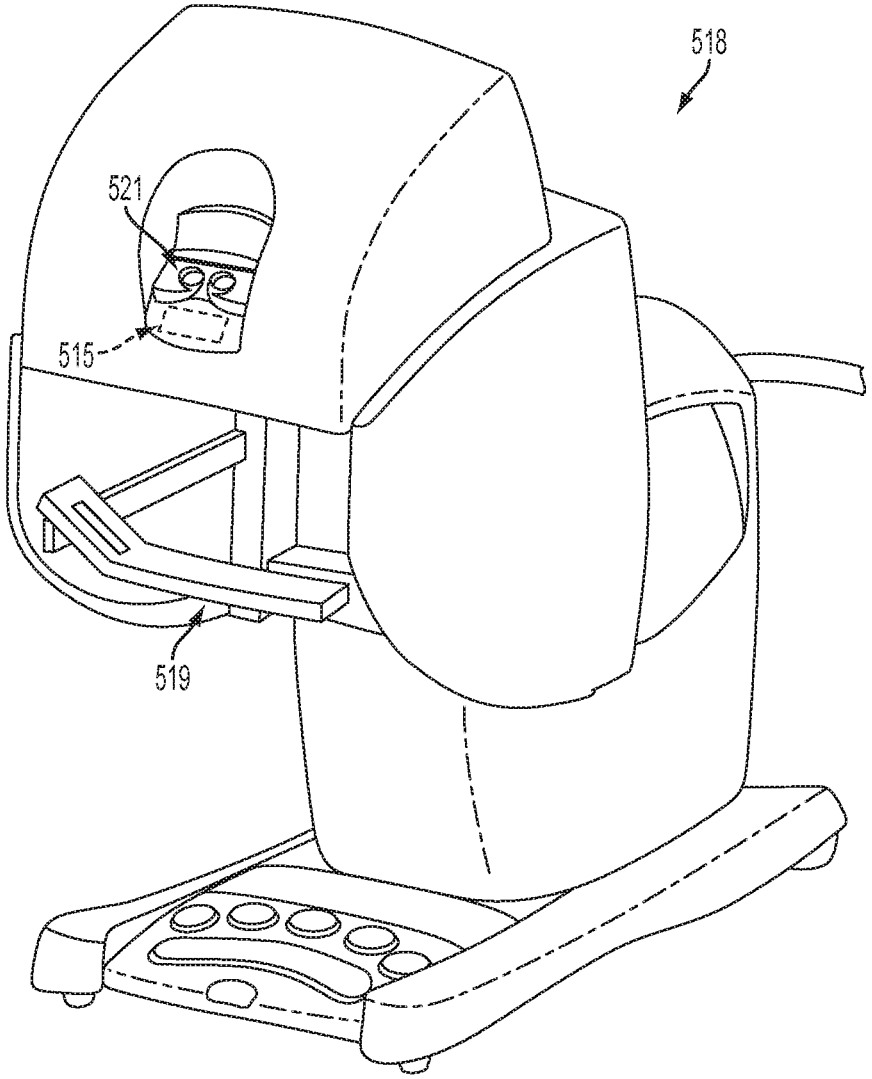



FIG. 15

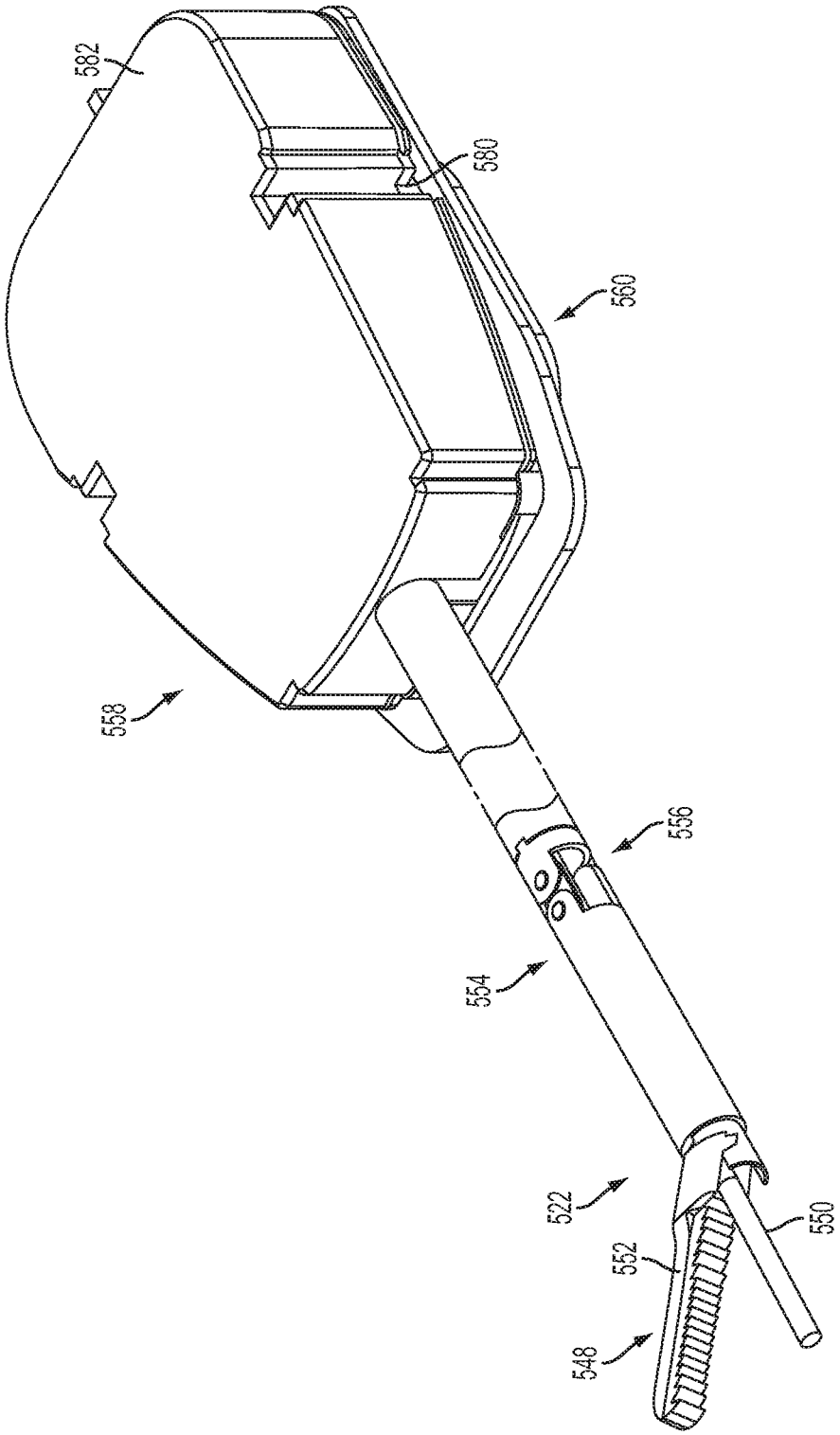
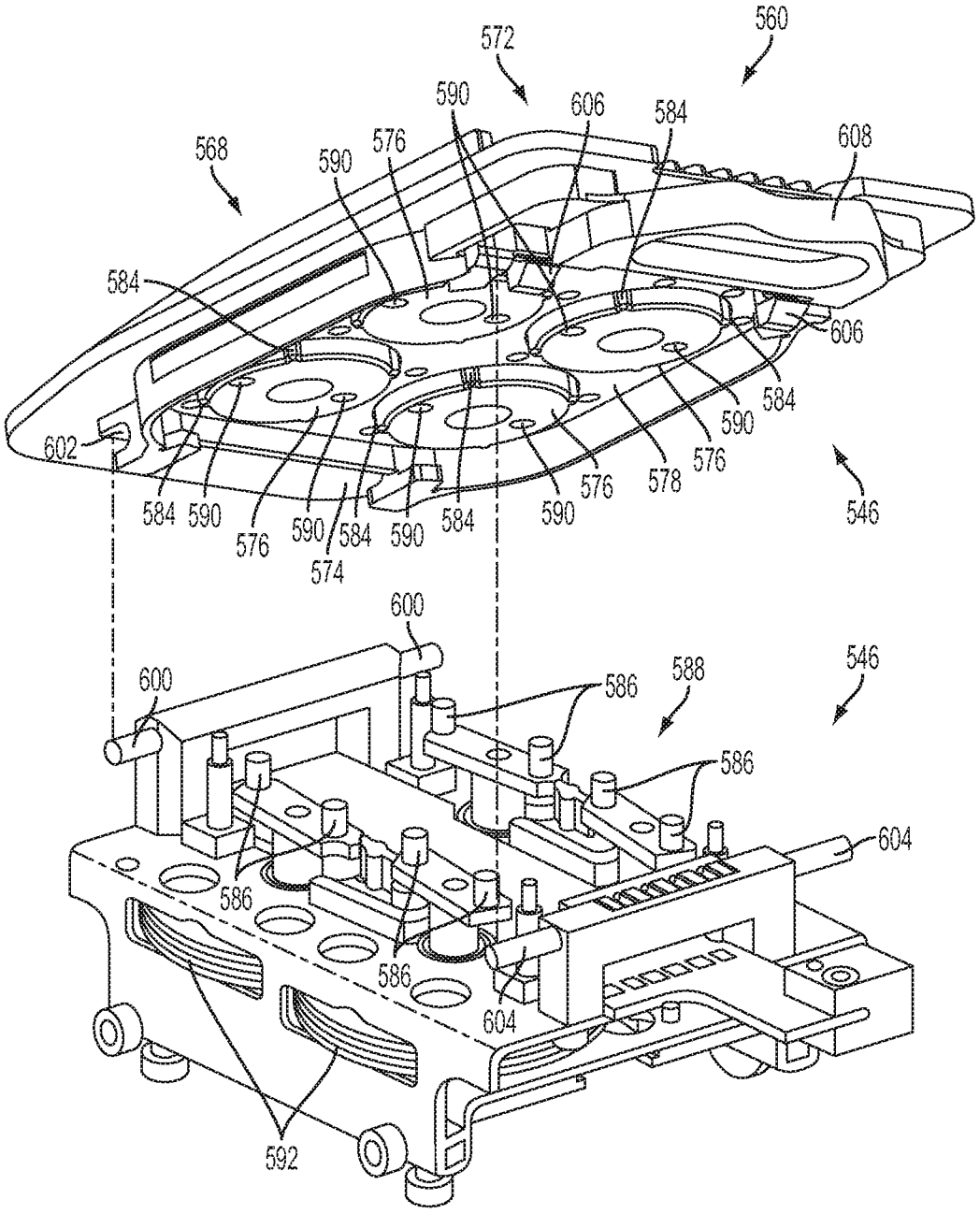



FIG. 16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584
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584
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584
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602
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578
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590
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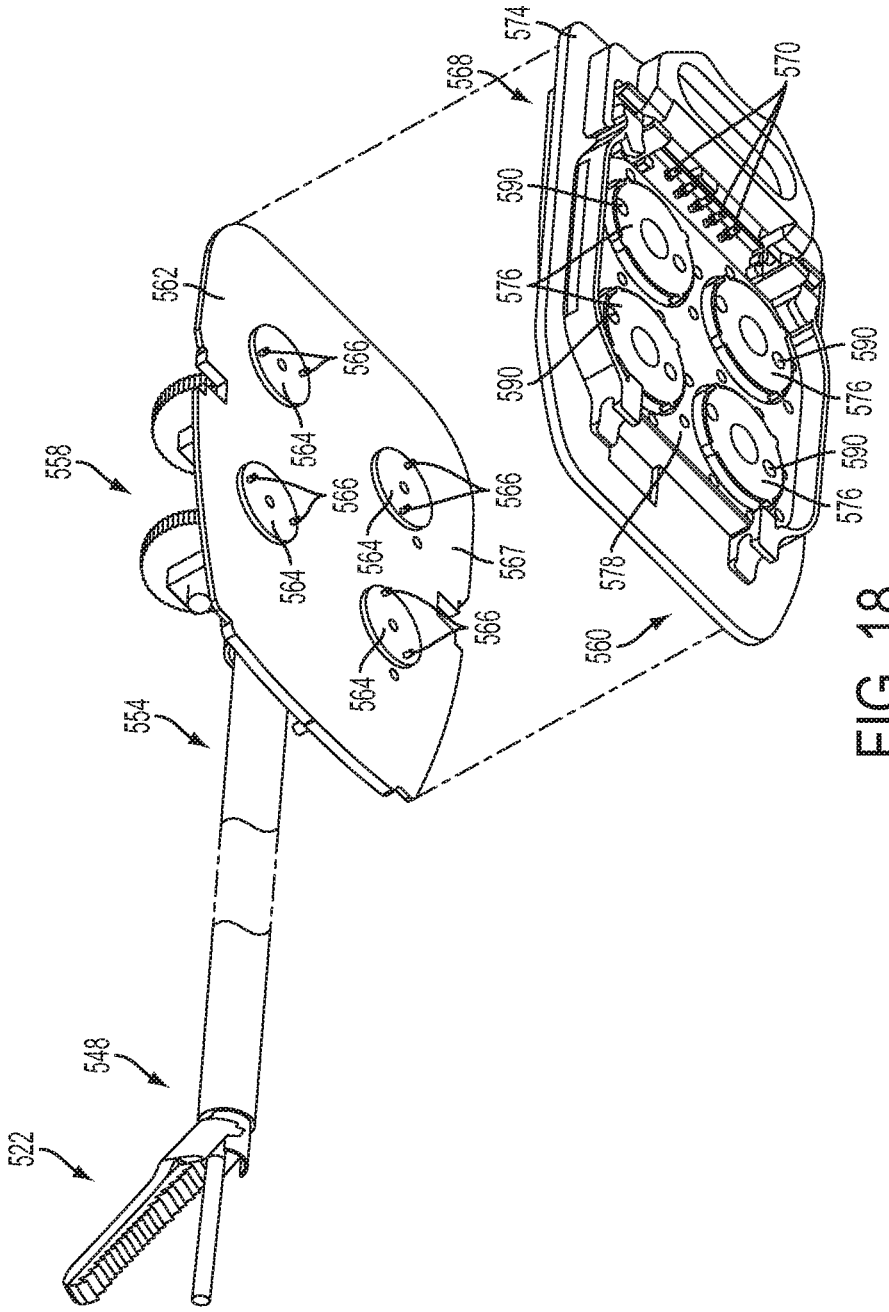
604
586
586
604
592

FIG. 17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568
570
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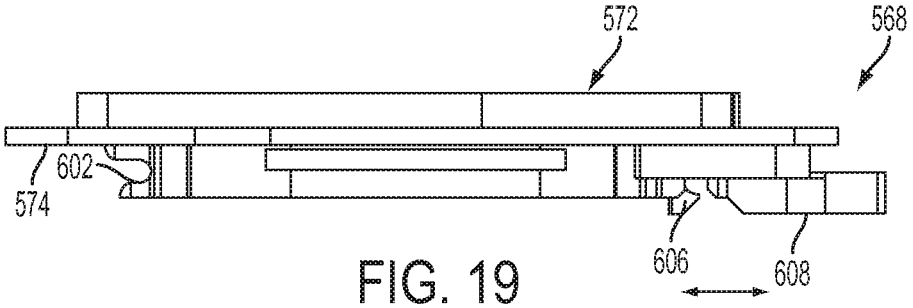
564
558
566
566
564
564
567
566
564
560
578
554
548
522

FIG. 18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606
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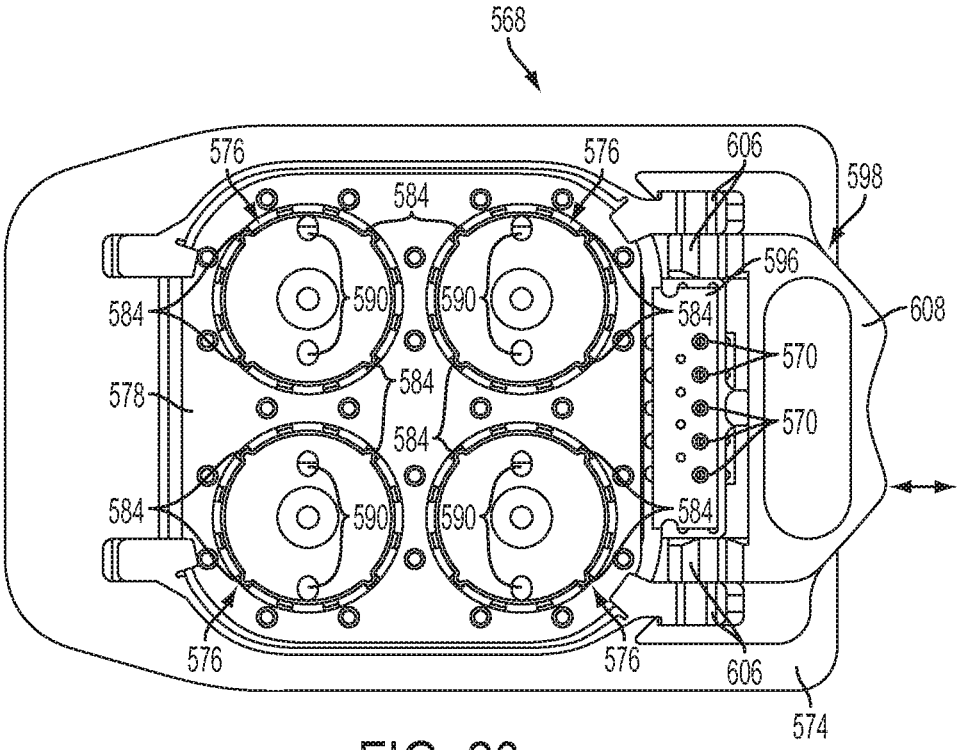
FIG. 19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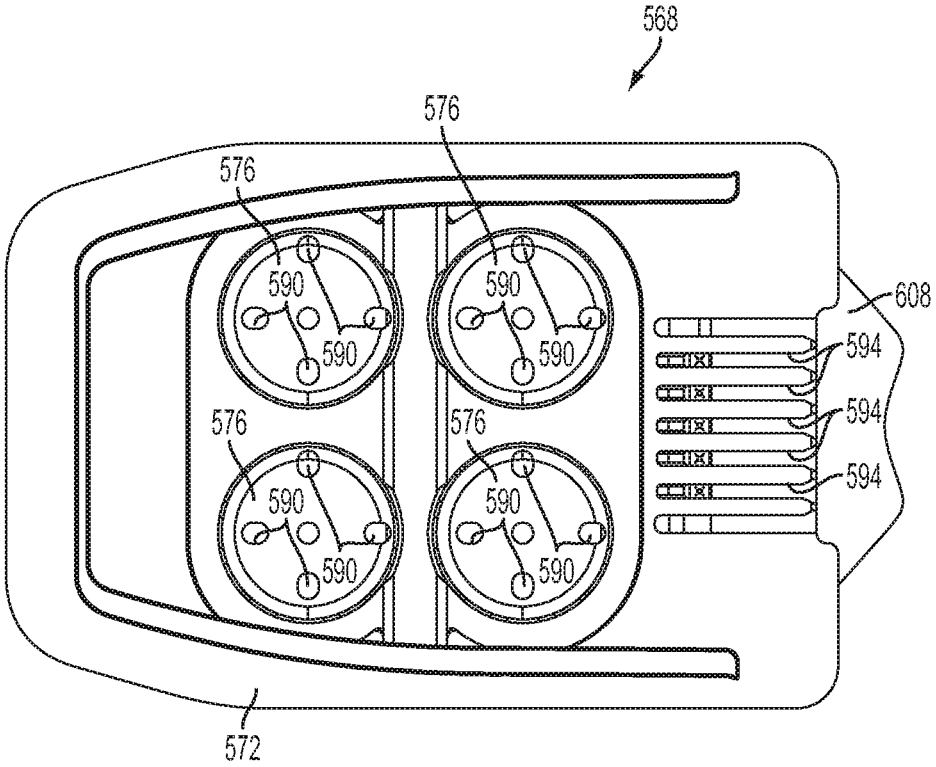
576
576
606
574

FIG. 20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590
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590
608
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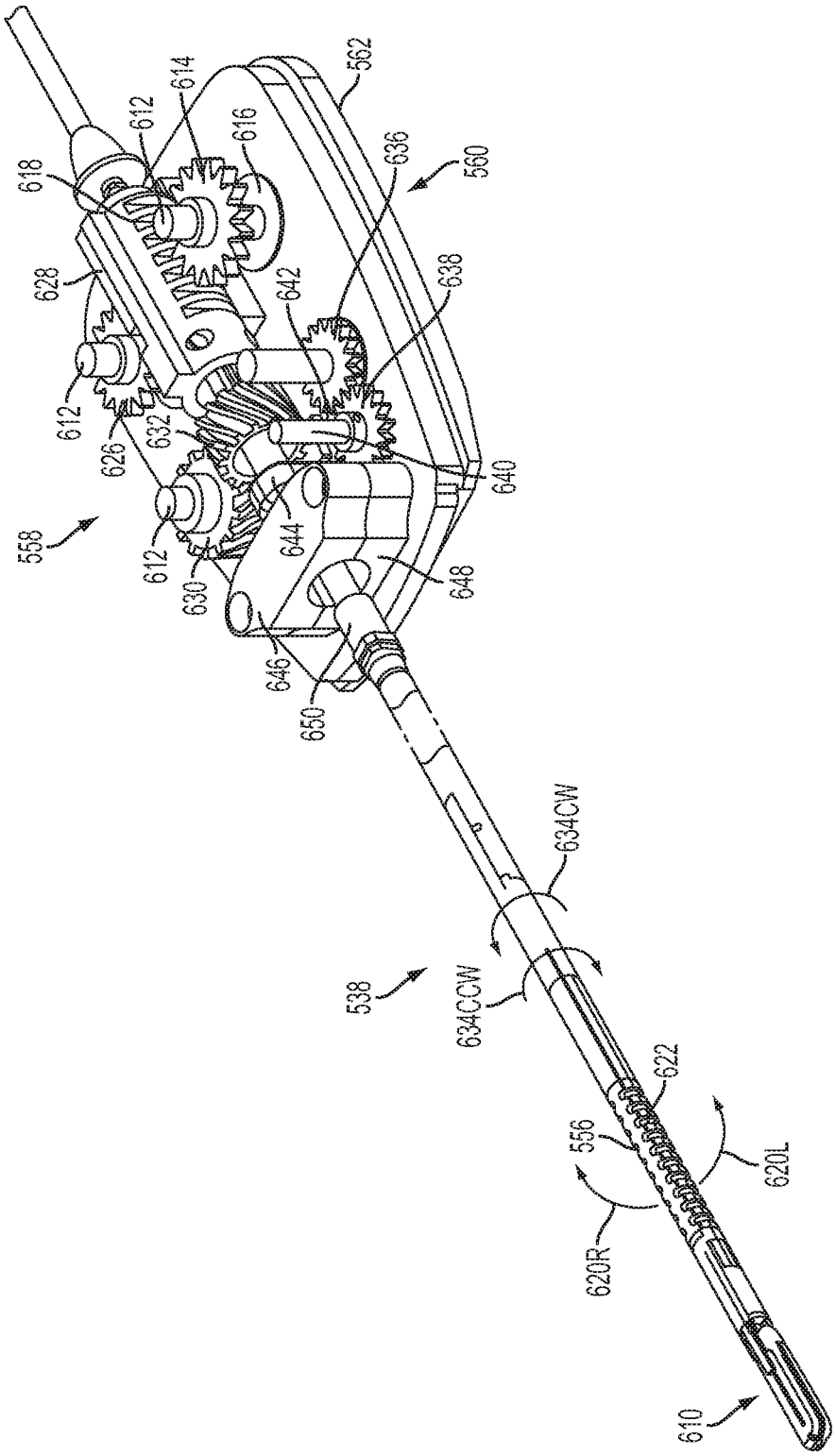
594
594
572

FIG. 21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616
618
560
636
628
642
638
612
632
626
640
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612
630
648
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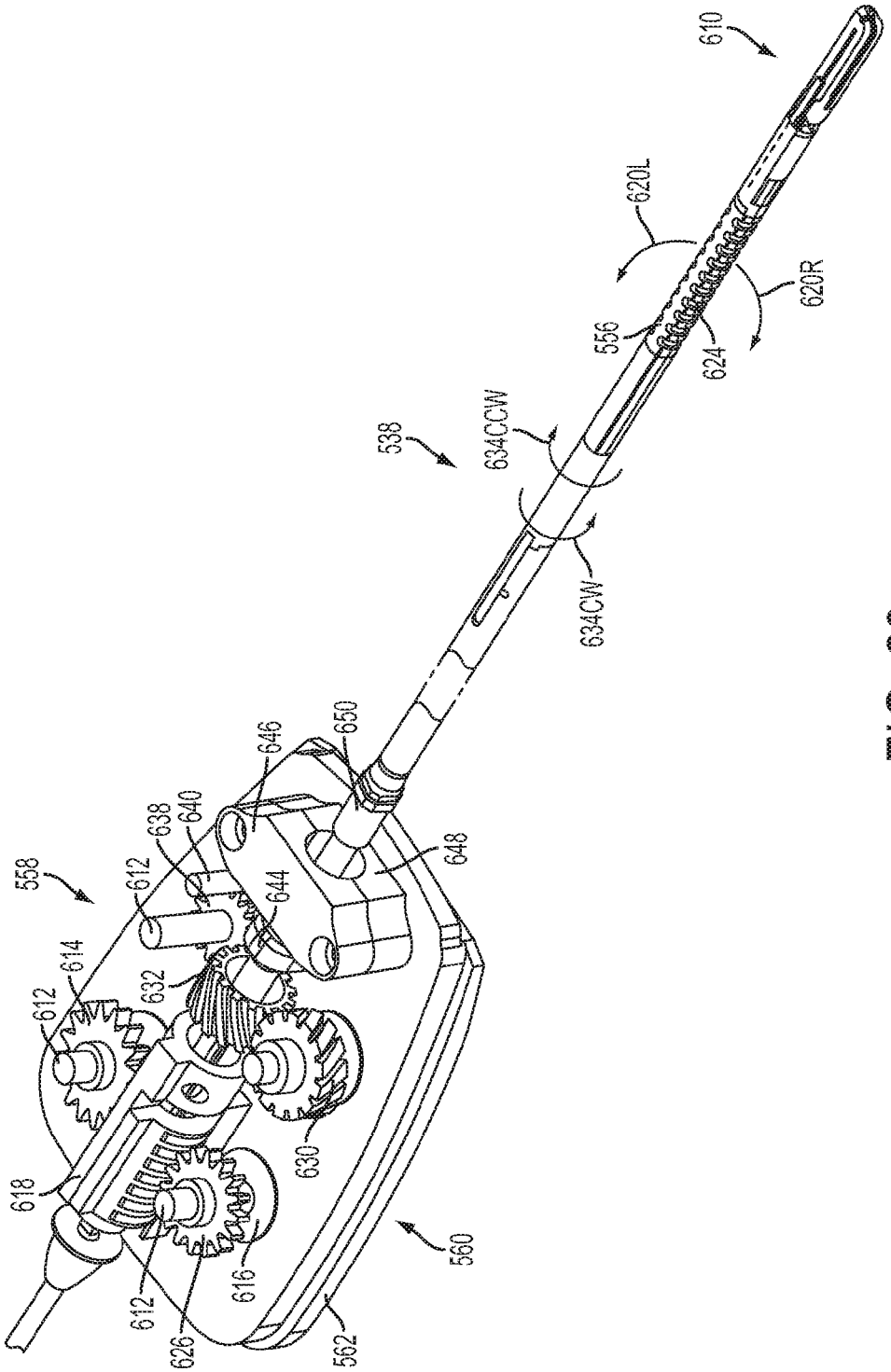
650
634CW
538
634CCW
622
556
620L
620R
610

FIG. 22


610
620L
620R
556
624
538
634CCW
634CW
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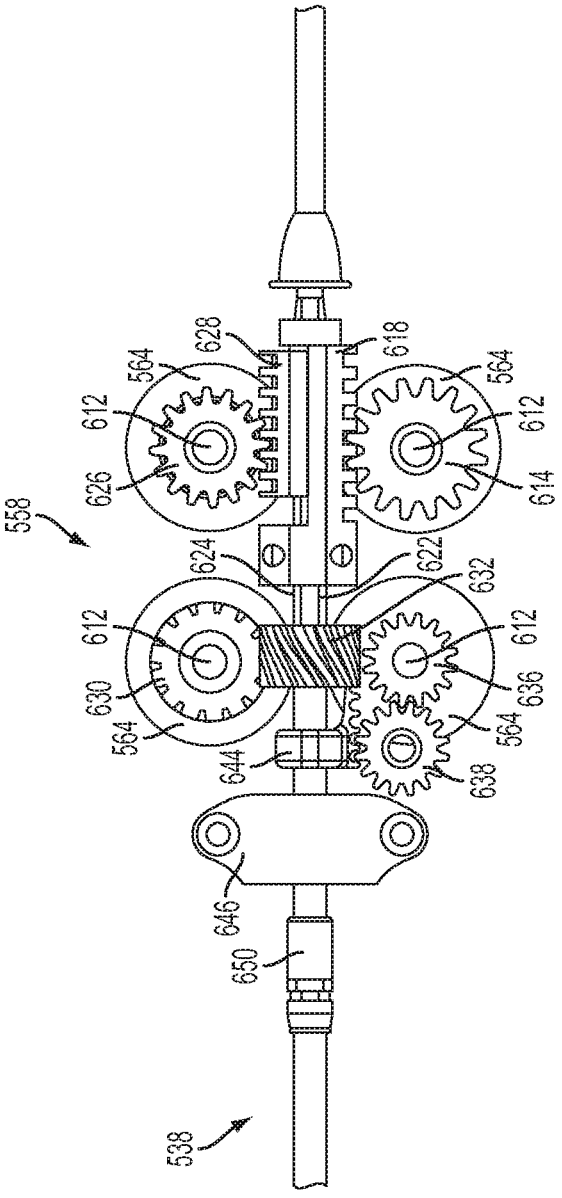
650
638
640
648
558
612
644
614
632
612
618
630
560
612
616
626
562

FIG. 23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626
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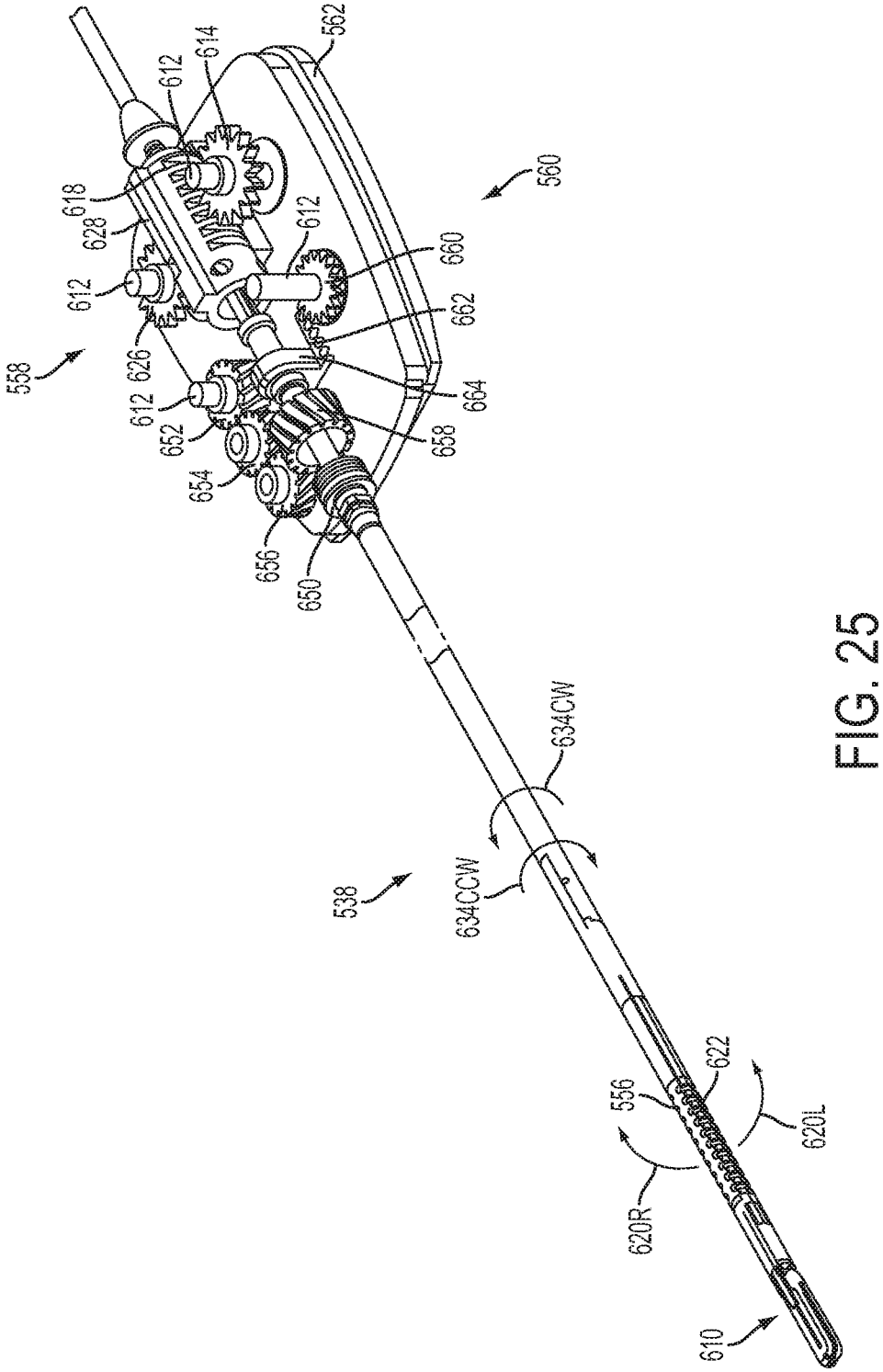
614
624
622
632
630
636
644
638
646
650

FIG. 24


562
614
612
618
628
612
612
626
612
652
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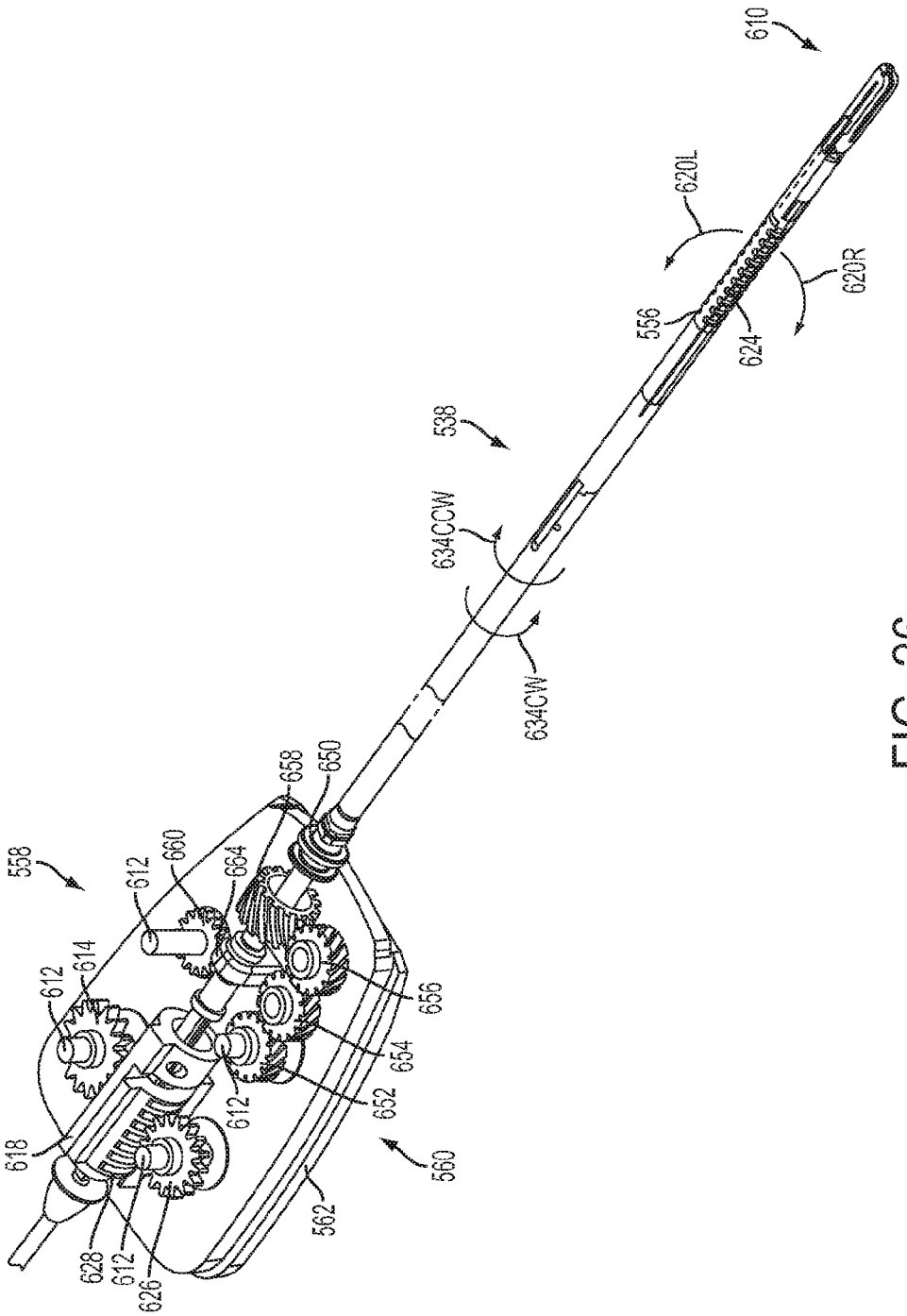
664
662
660
560
558
538
634CW
634CCW
622
556
620L
620R
610

FIG. 25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620L
620R
556
624
538
634CCW
634CW
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612
660
664
614
612
656
654
612
652
618
560
562
628
612
626

FIG. 26

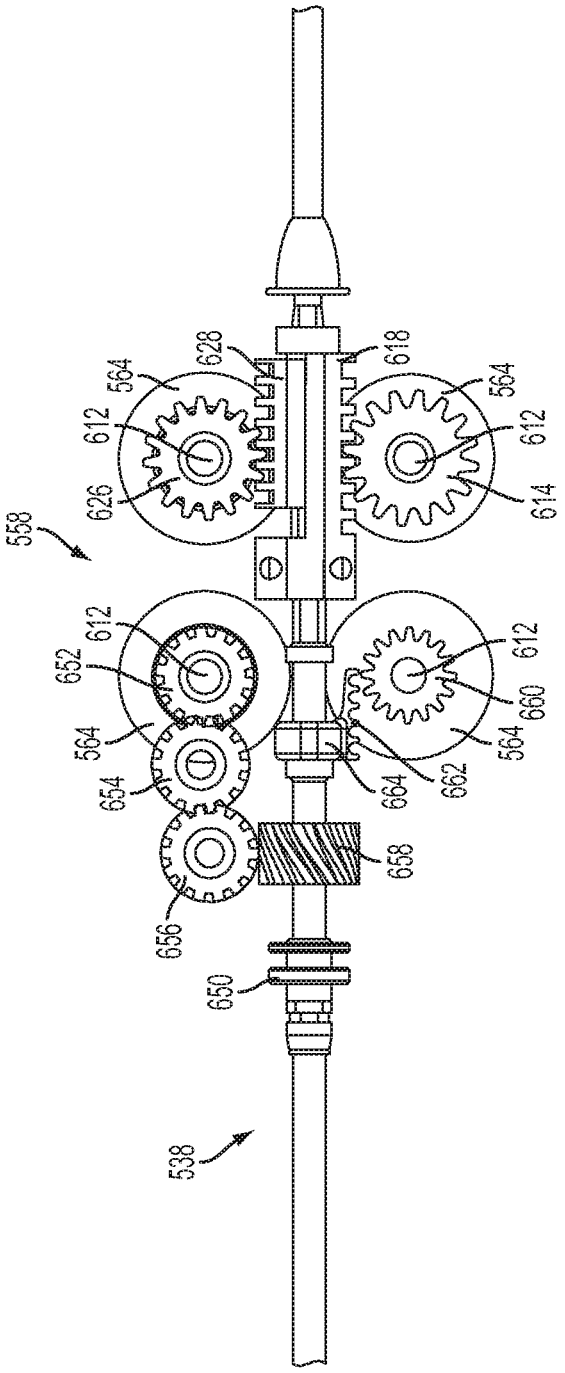

558
564
628
618
564
612
612
626
614
612
652
612
564
660
564
654
662
664
658
656
650
538

FIG. 27

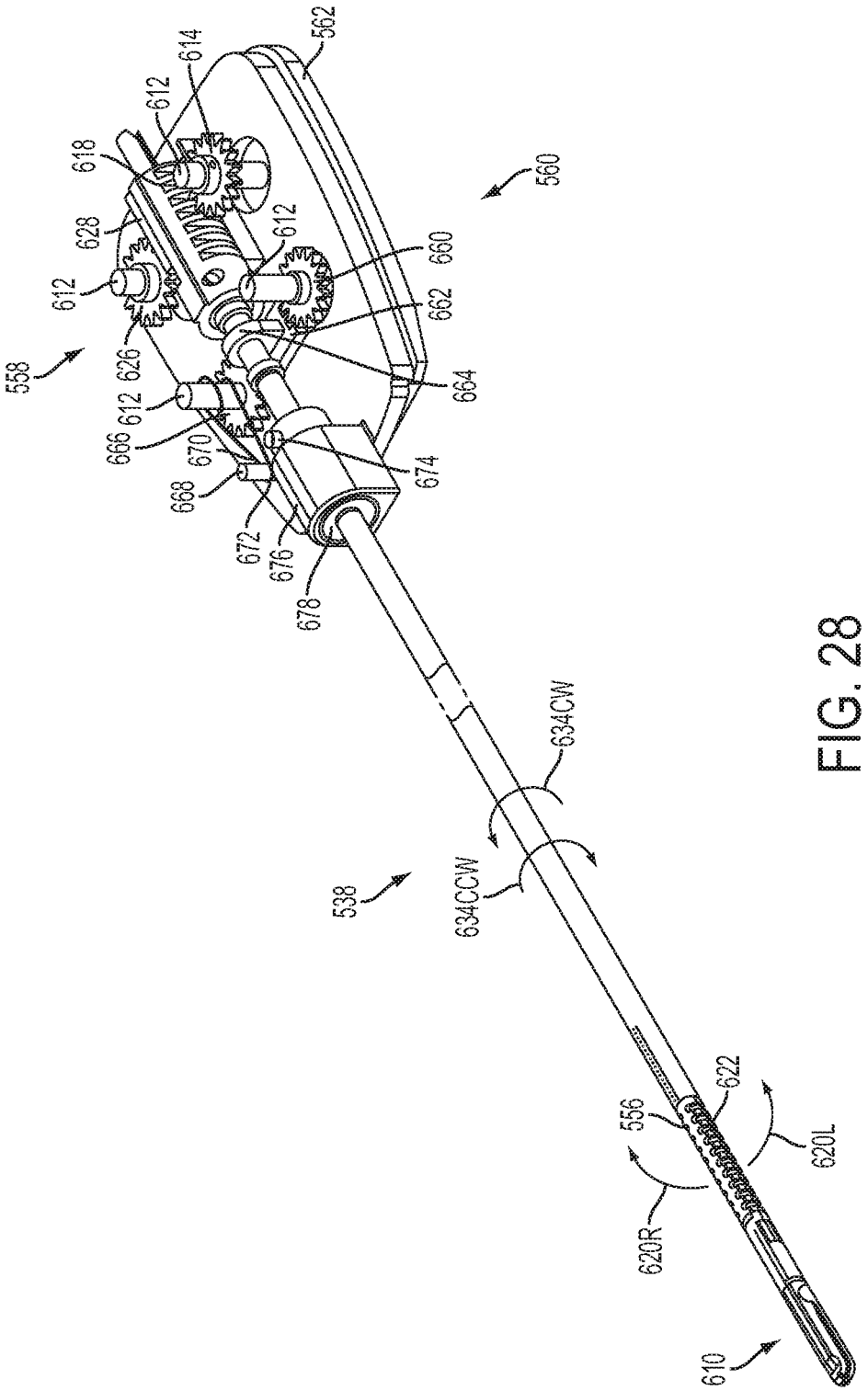
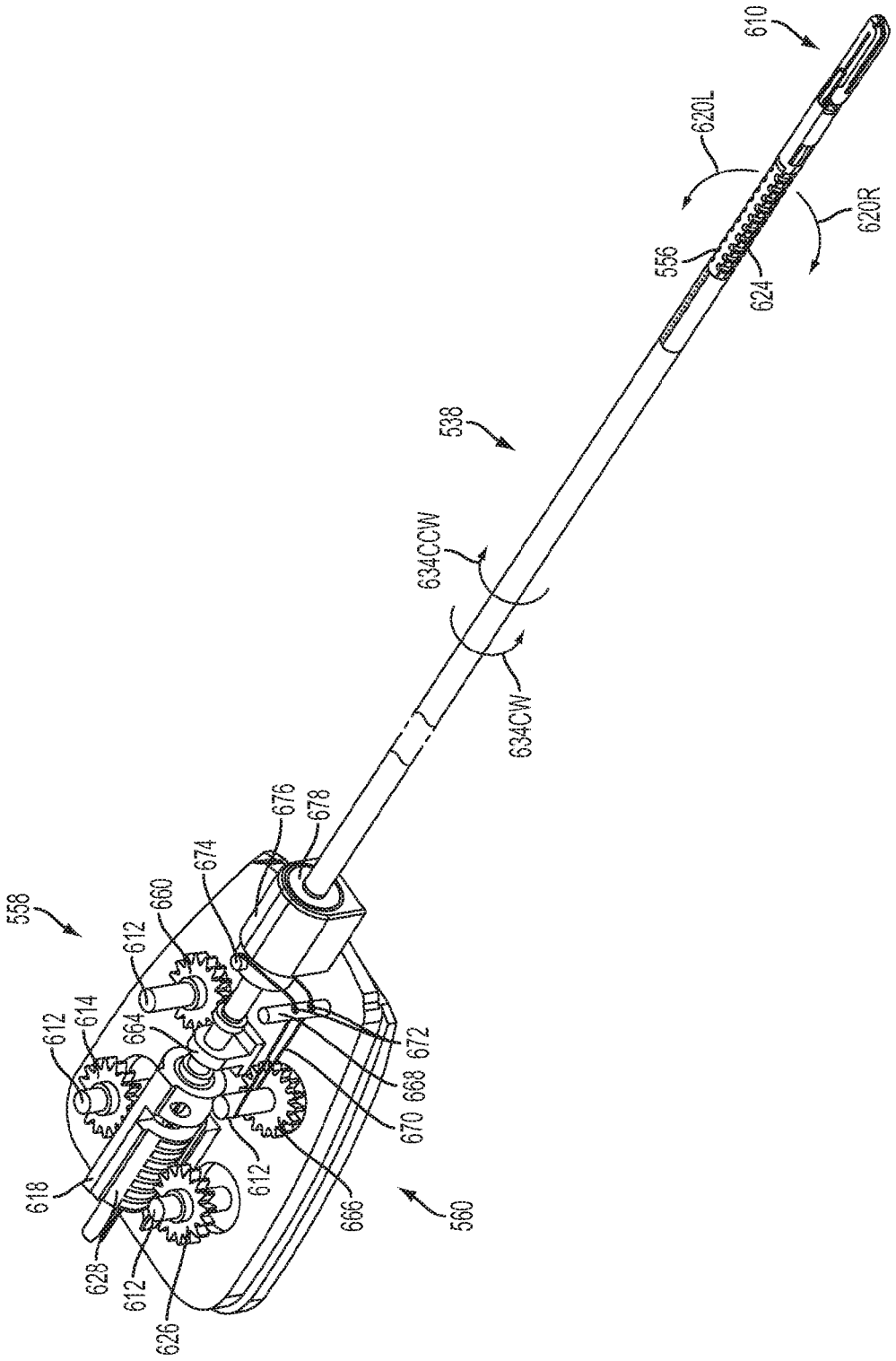

562
614
612
618
560
628
612
660
612
662
626
664
558
612
666
670
674
668
672
676
678
634CW
538
634CCW
622
556
620L
620R
610

FIG. 28


610
620L
620R
556
624
538
634CCW
634CW
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678
674
660
612
614
664
672
668
670
666
560
558
618
628
626

FIG. 29

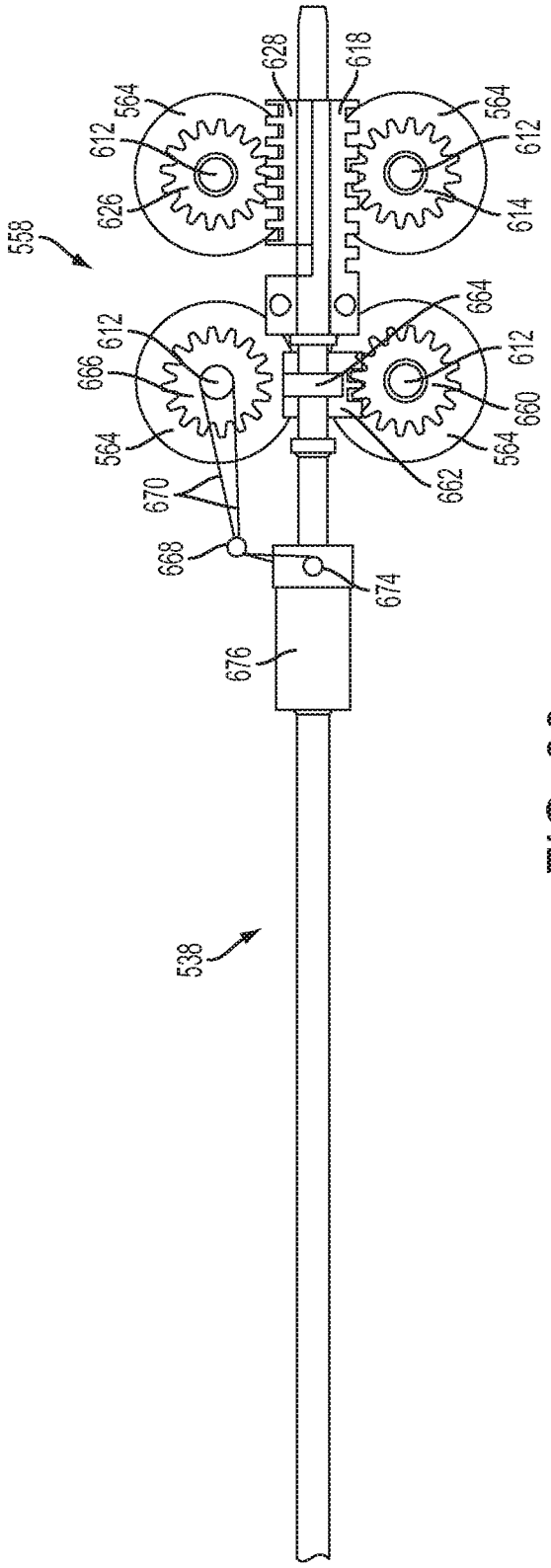



FIG. 30

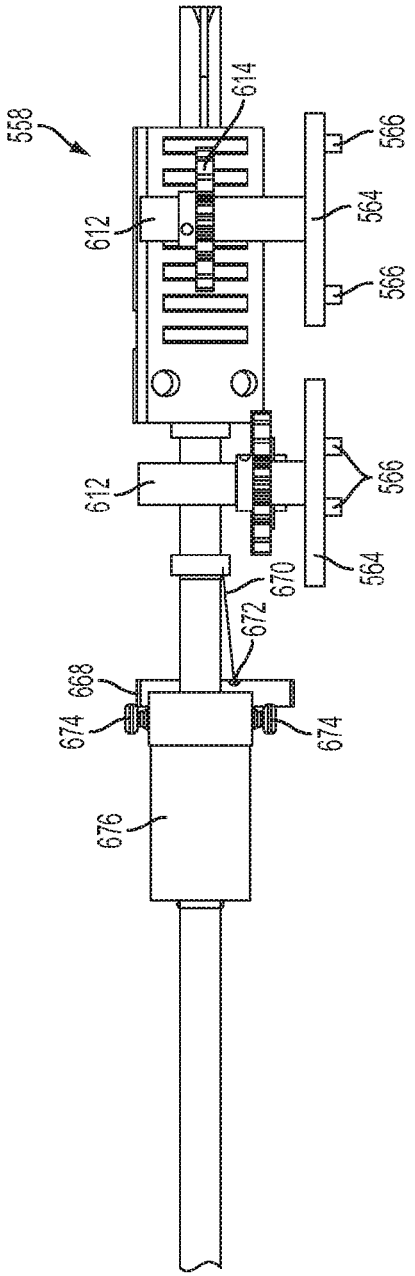
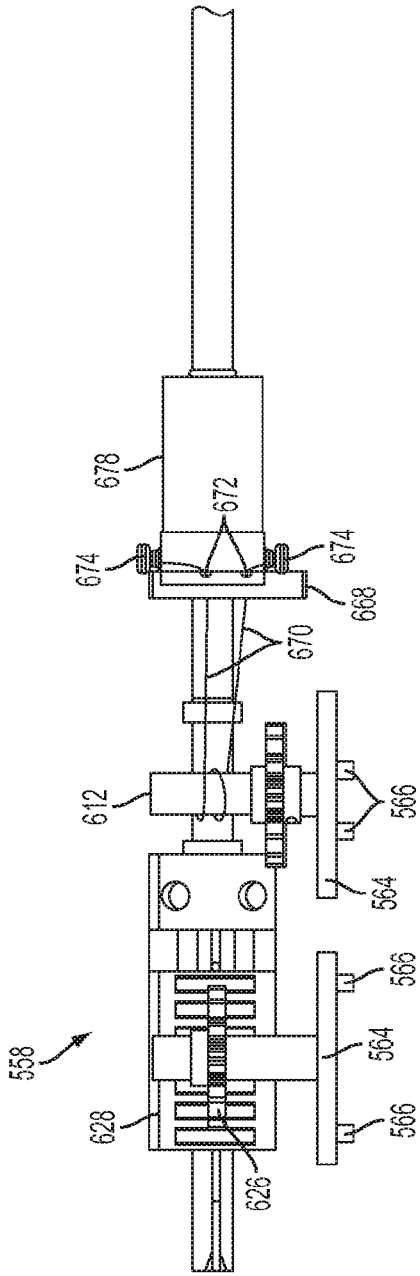

558
614
566
564
612
566
612
566
564
670
672
668
674
674
676

FIG. 31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674
674
668
670
612
566
564
566
564
558
628
626
566

FIG. 32

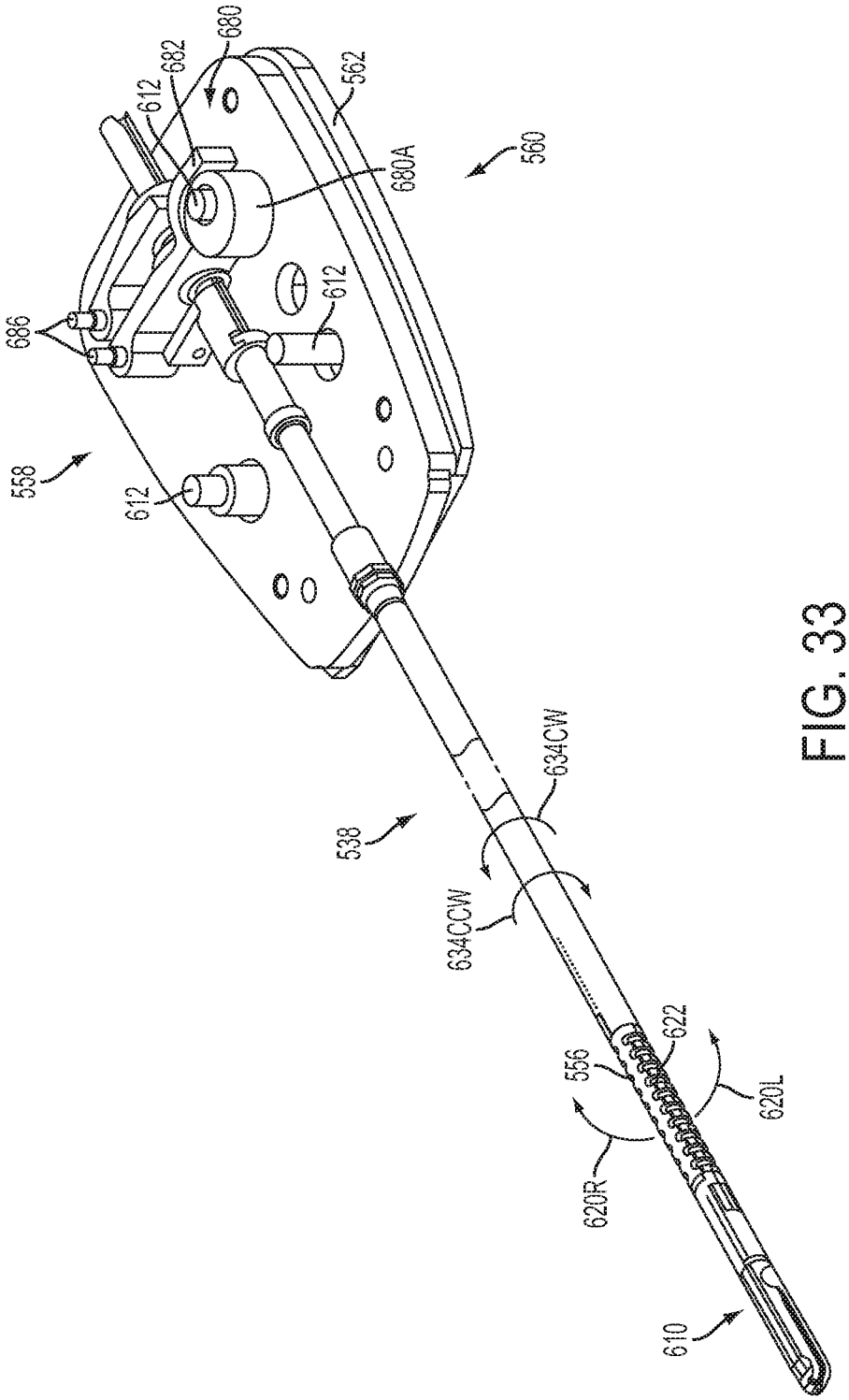

680
682
612
562
560
680A
612
686
558
612
538
634CW
634CCW
622
556
620L
620R
610

FIG. 33

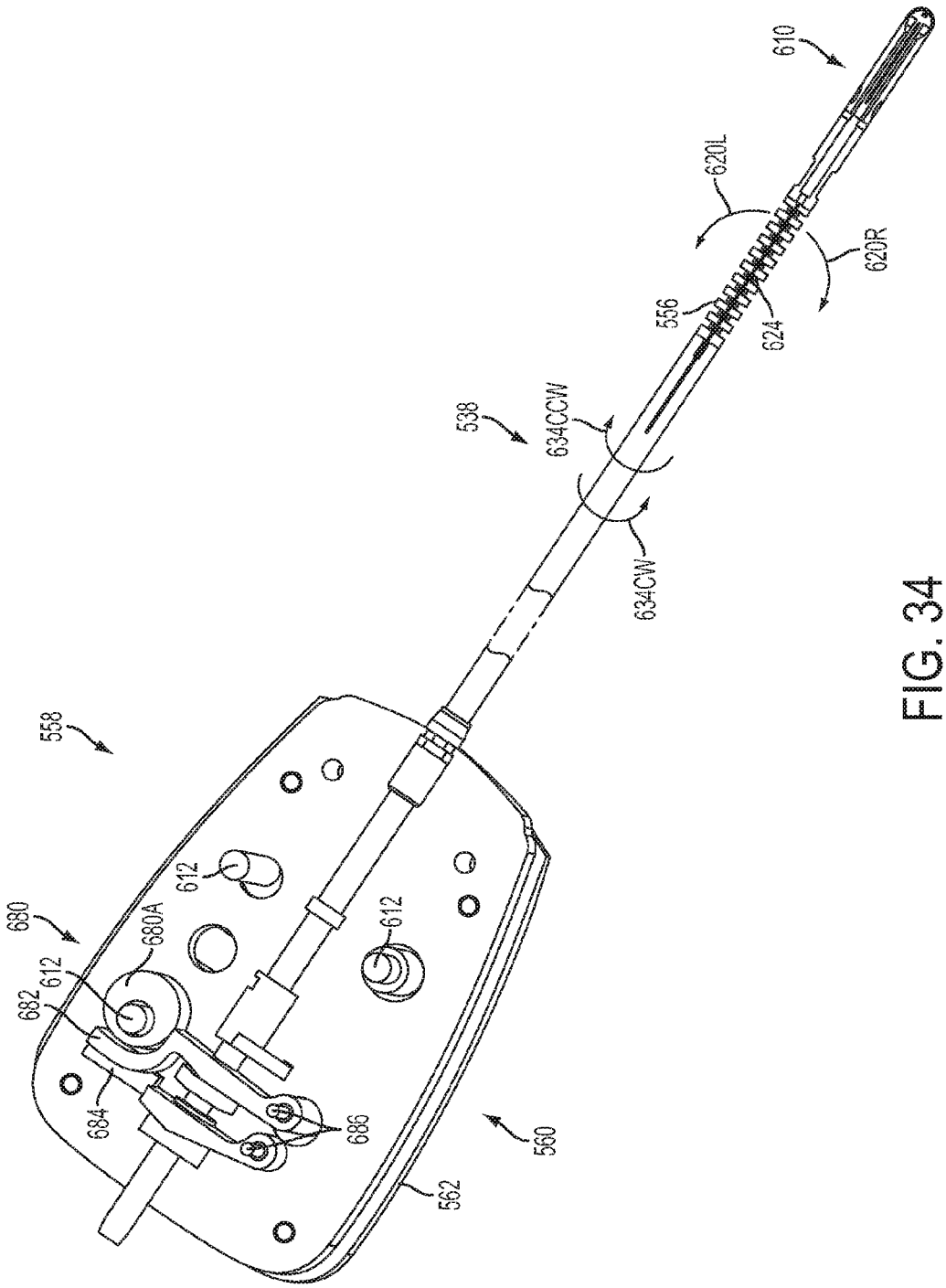

610
620L
620R
556
624
538
634CCW
634CW
558
612
680
680A
612
682
612
684
686
560
562

FIG. 34

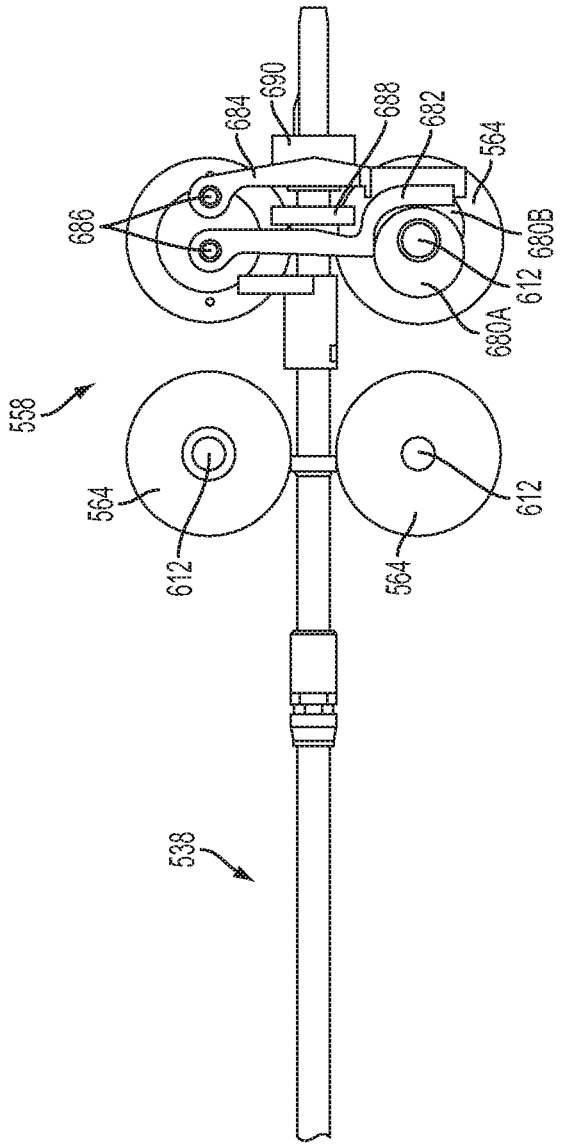



FIG. 35

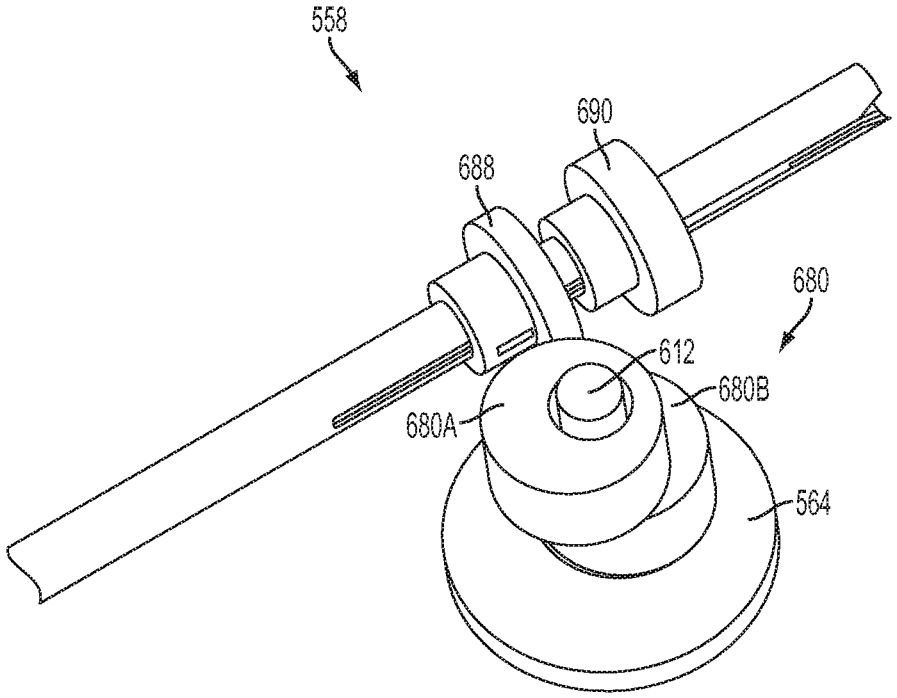



FIG. 36A

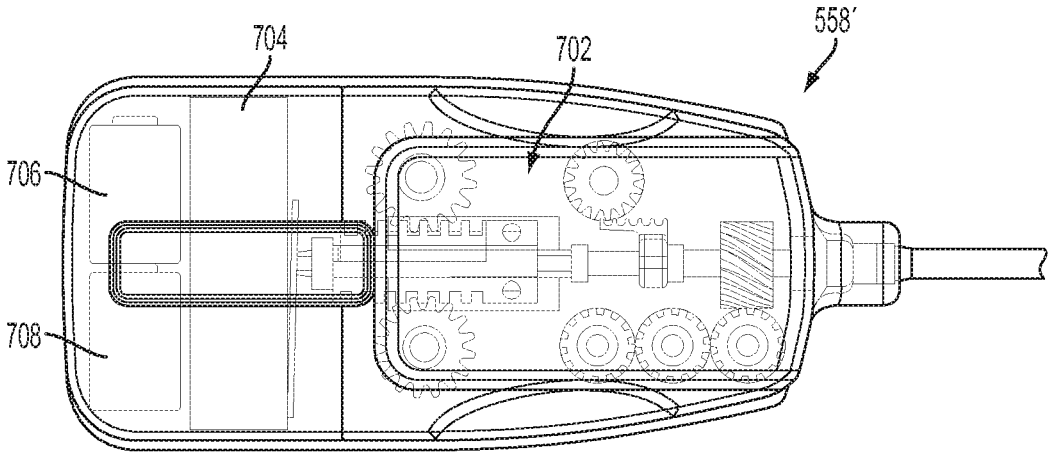



FIG. 36B

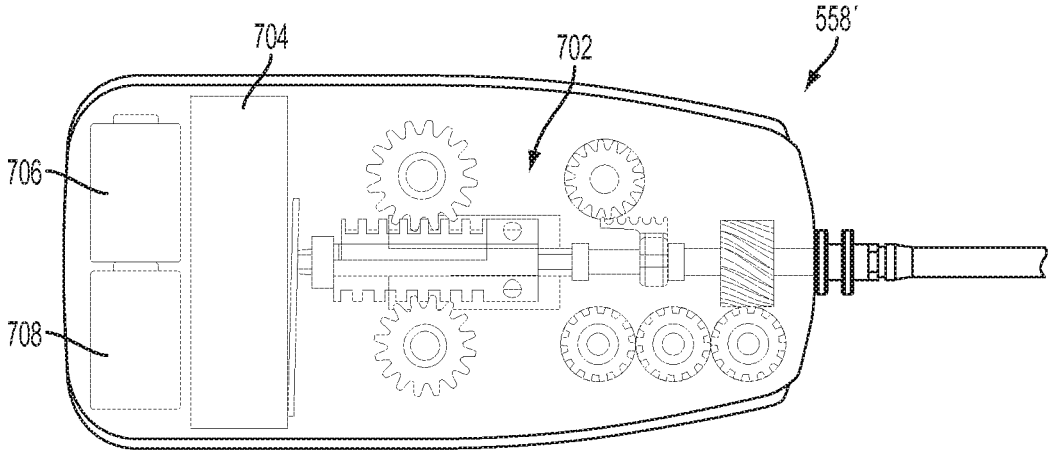
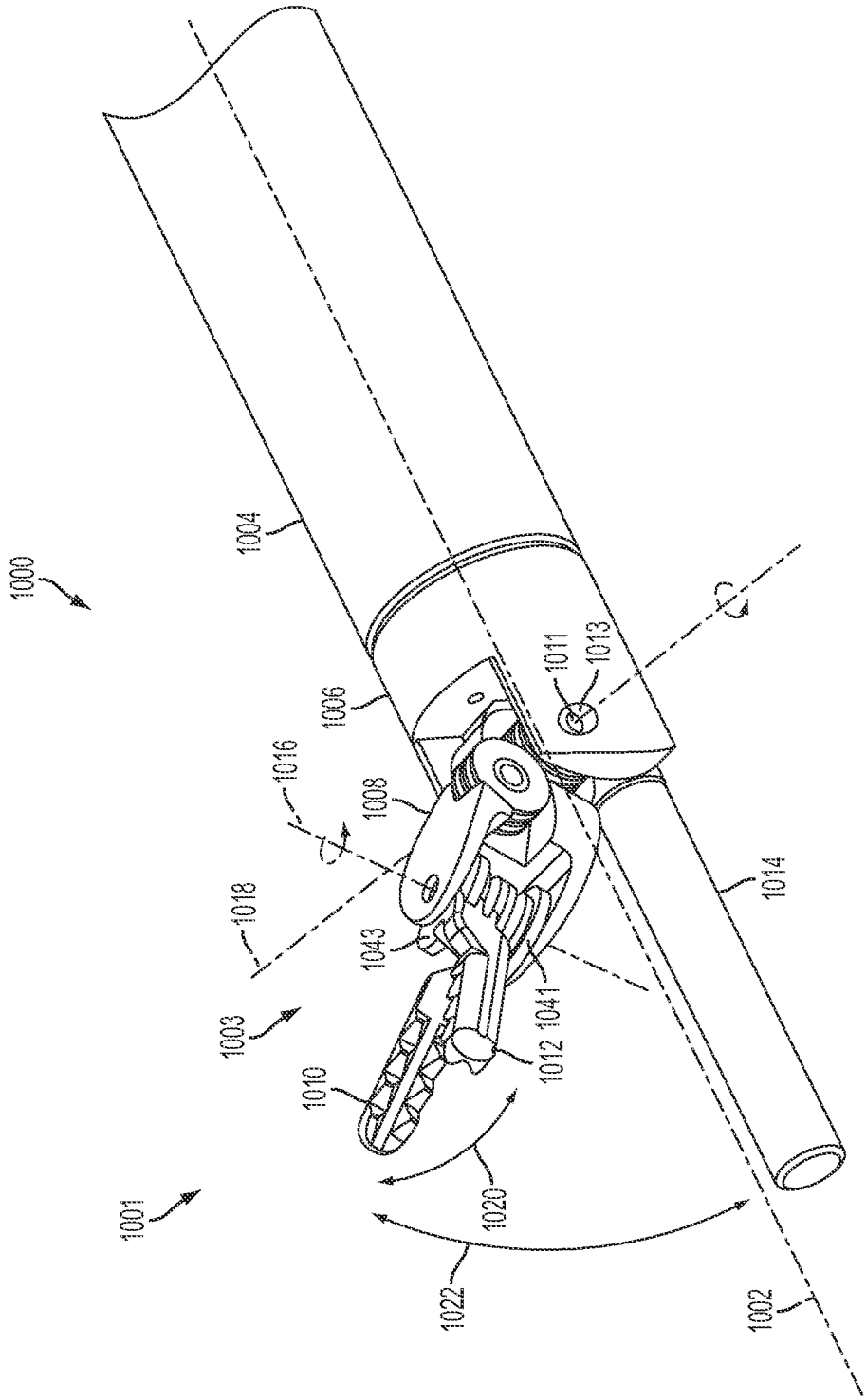



FIG. 36C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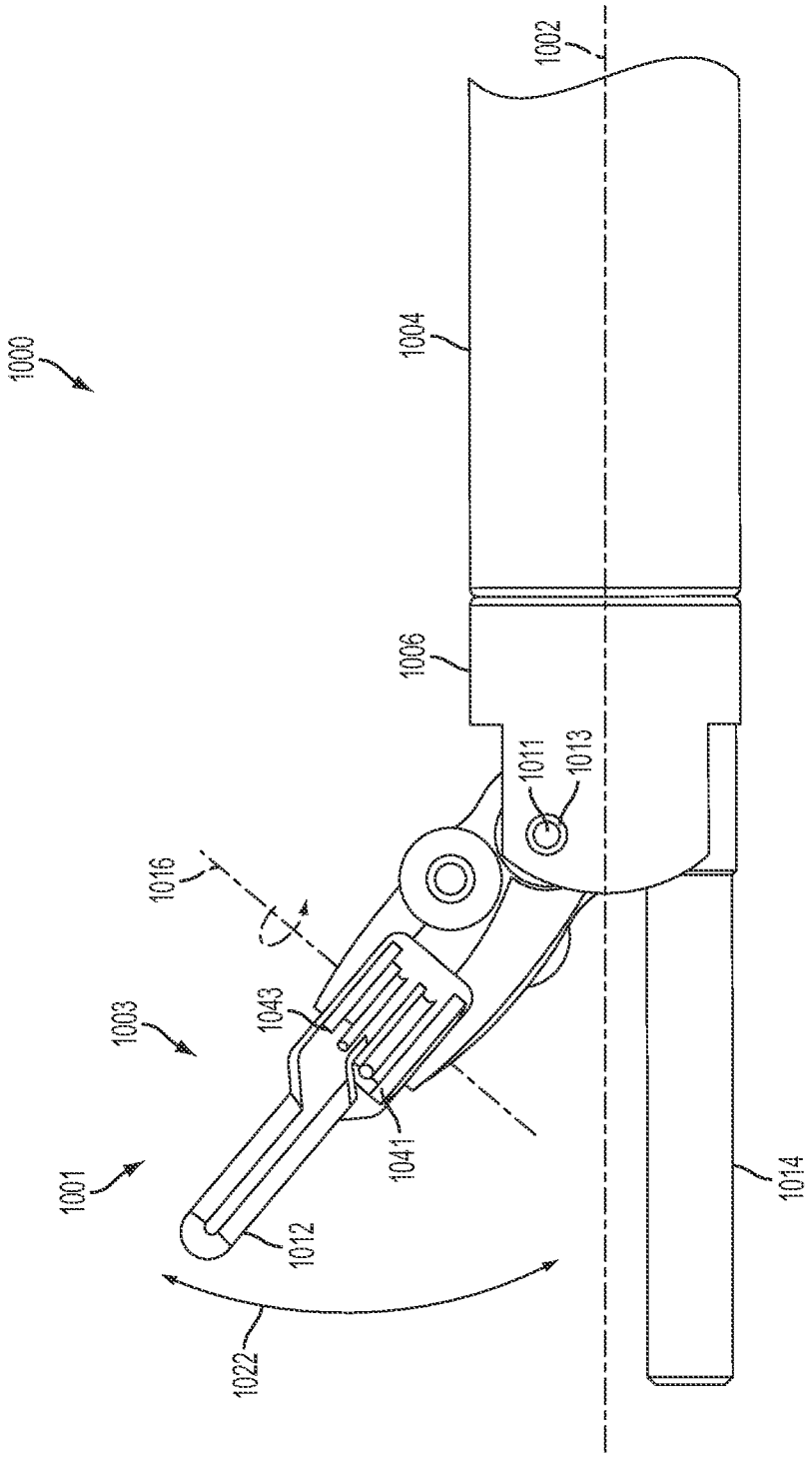
1004
1006
1011
1013
1016
1008
1018
1043
1003
1041
1012
1010
1014
1001
1020
1022
1002

FIG. 37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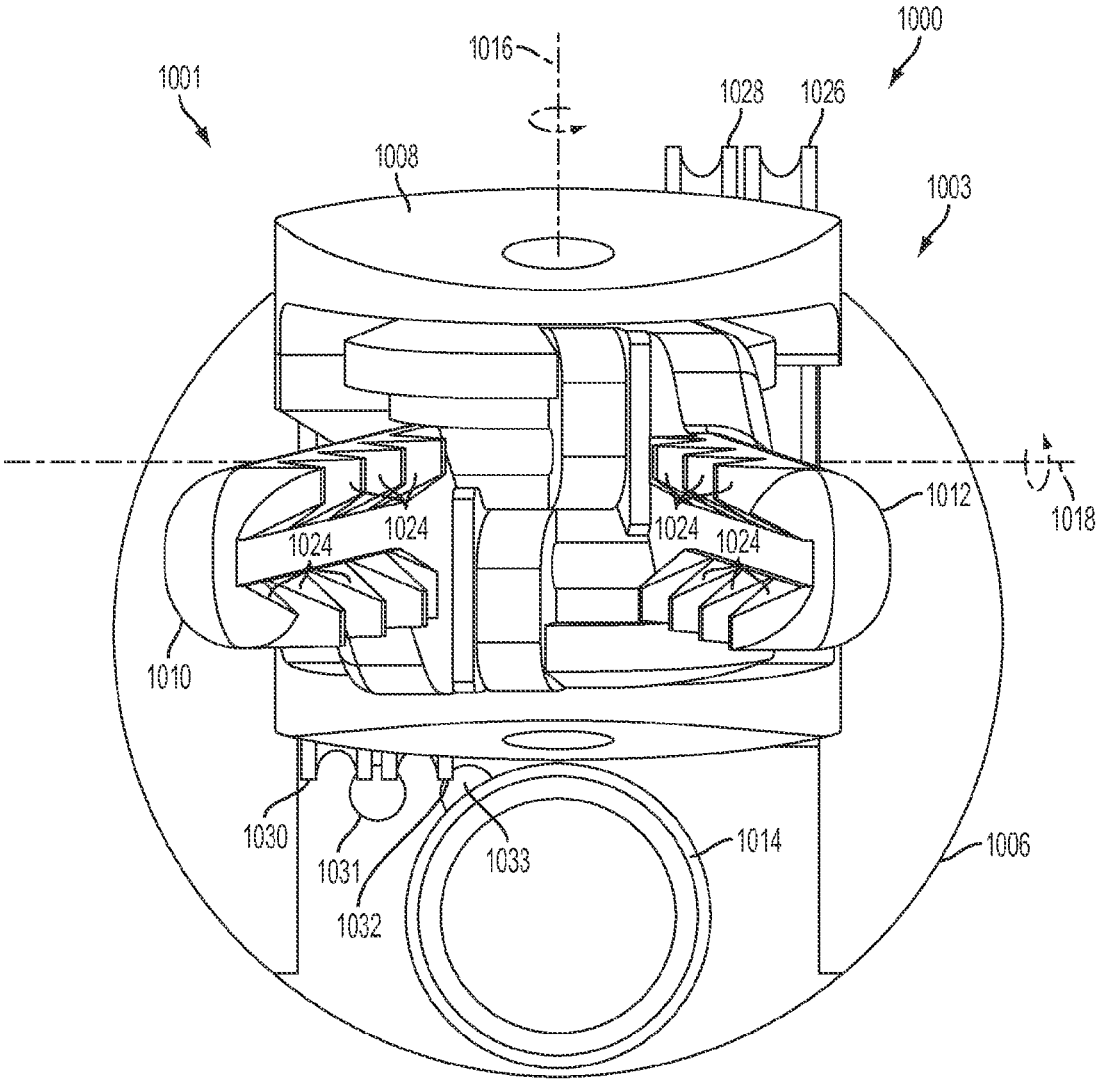
1006
1011
1012
1013
1014
1016
1022
1041
1043

FIG. 38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1024
1024
1010
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1031
1032
1033
1014
1006

FIG. 39

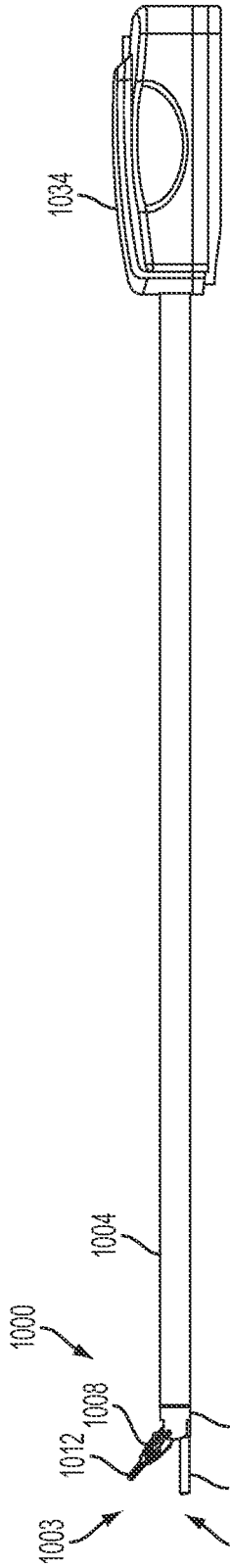



FIG. 40

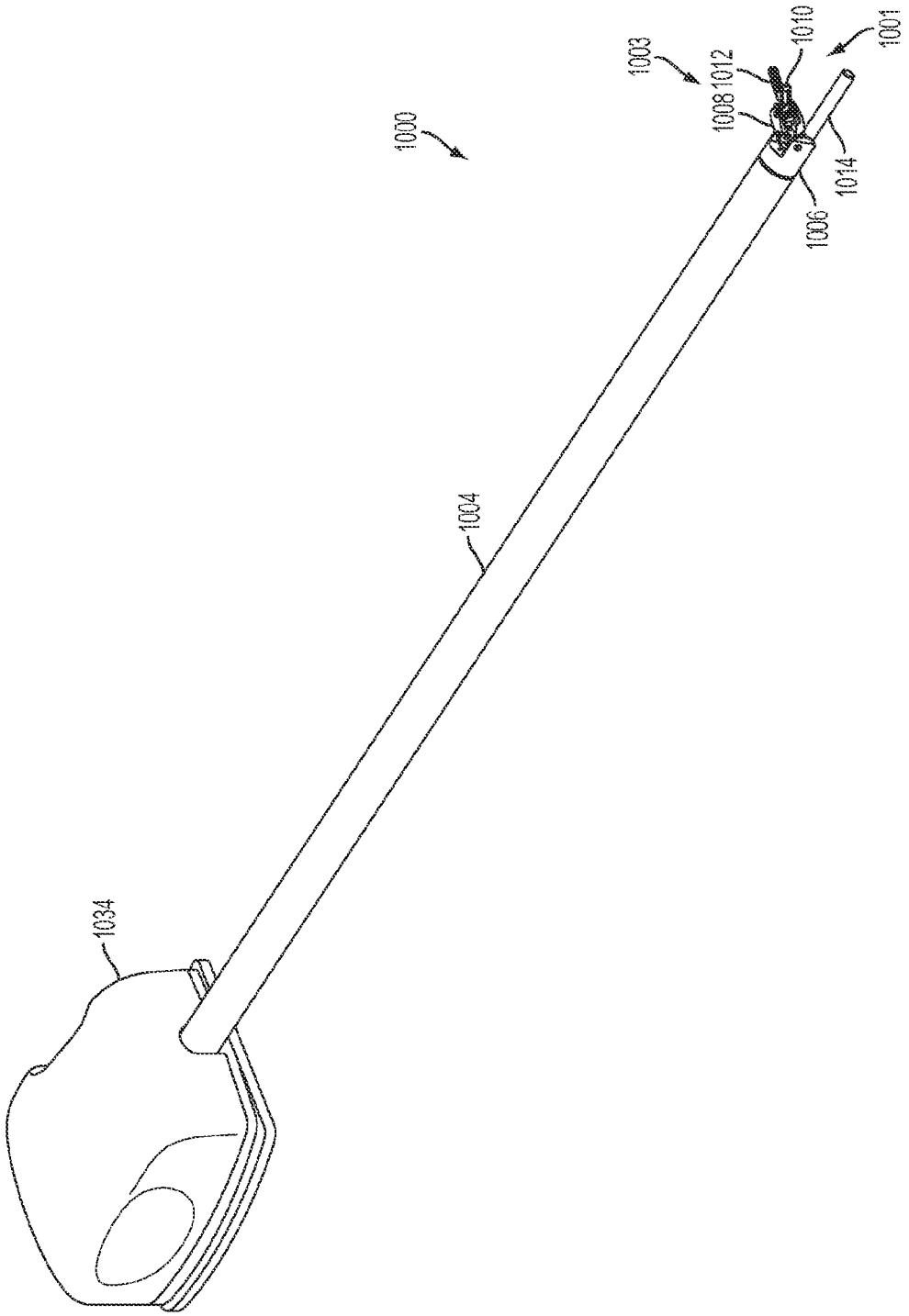
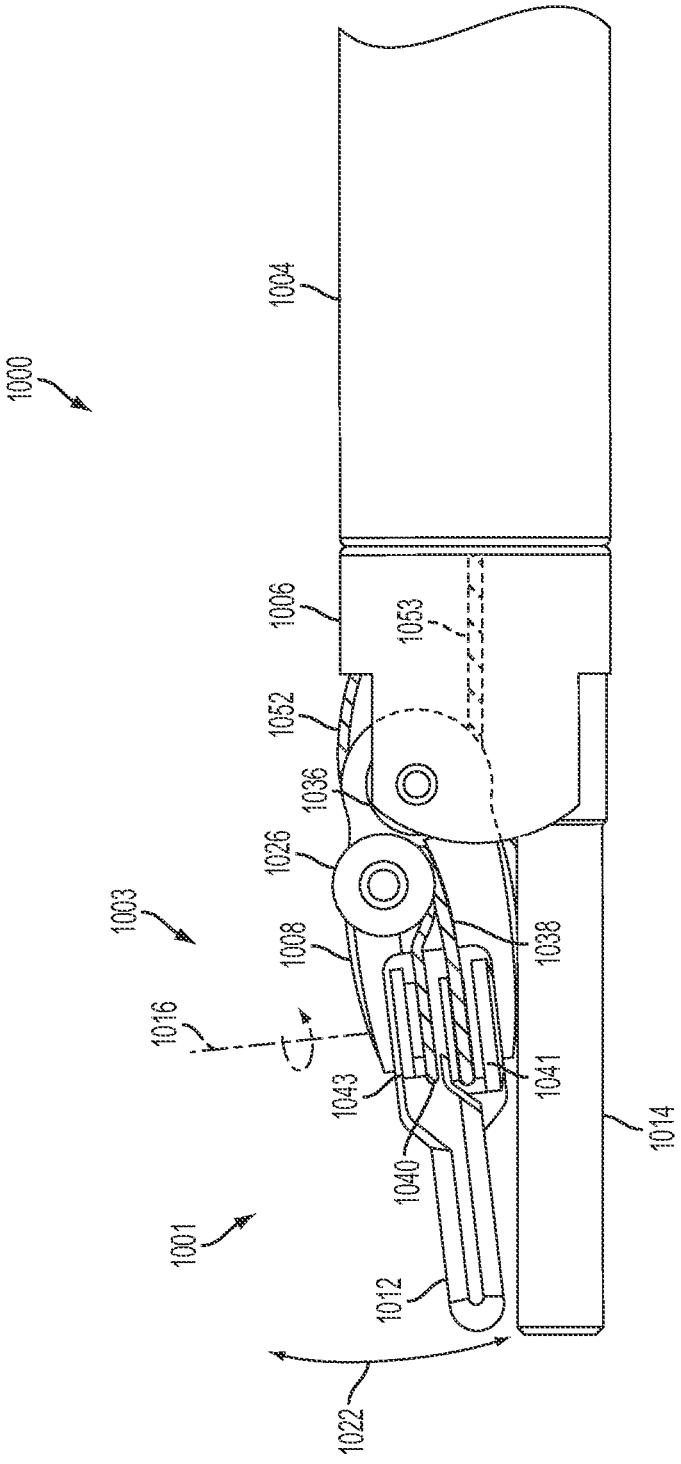



FIG. 41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1016
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1014
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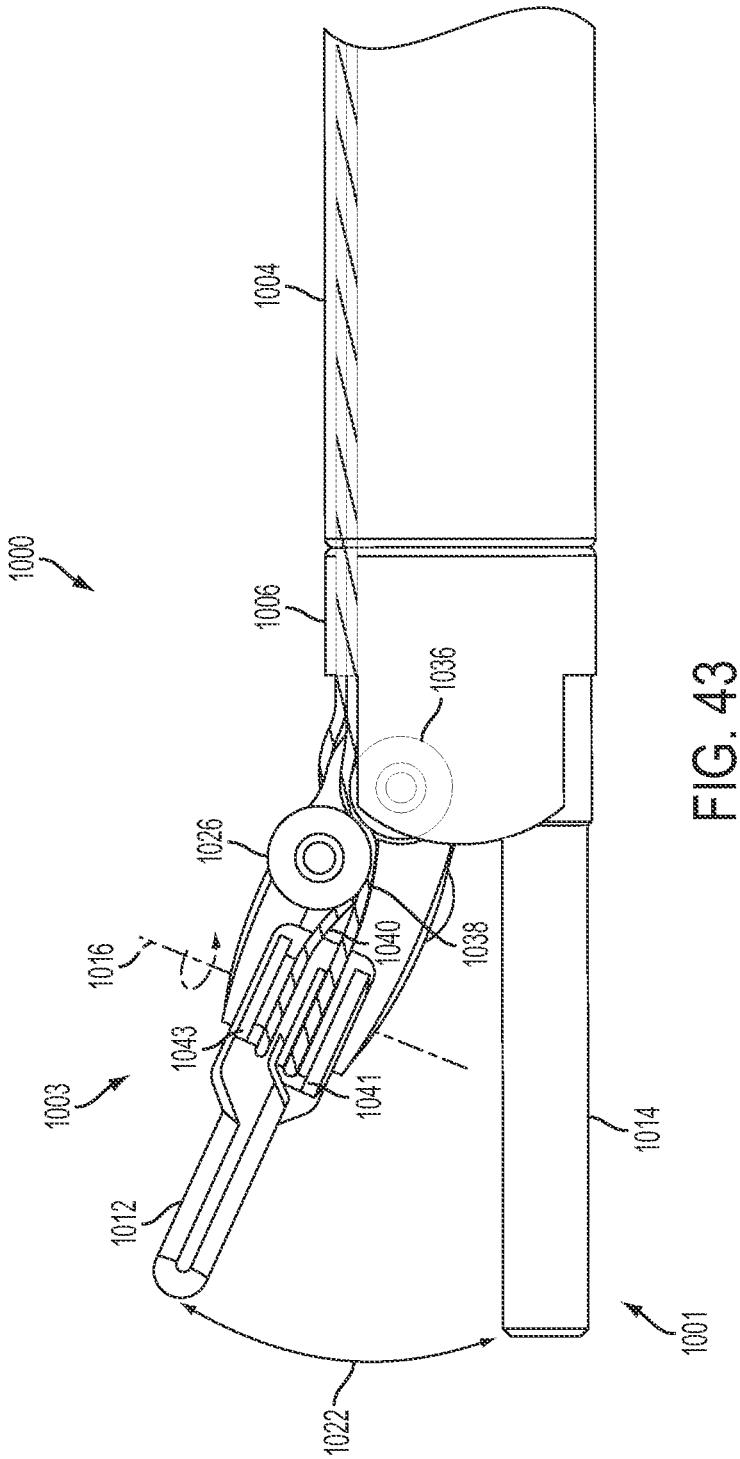
1001
1012
1022

FIG. 42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1004
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1036
1026
1016
1040
1038
1043
1041
1003
1014
1012
1001
1022

FIG. 43

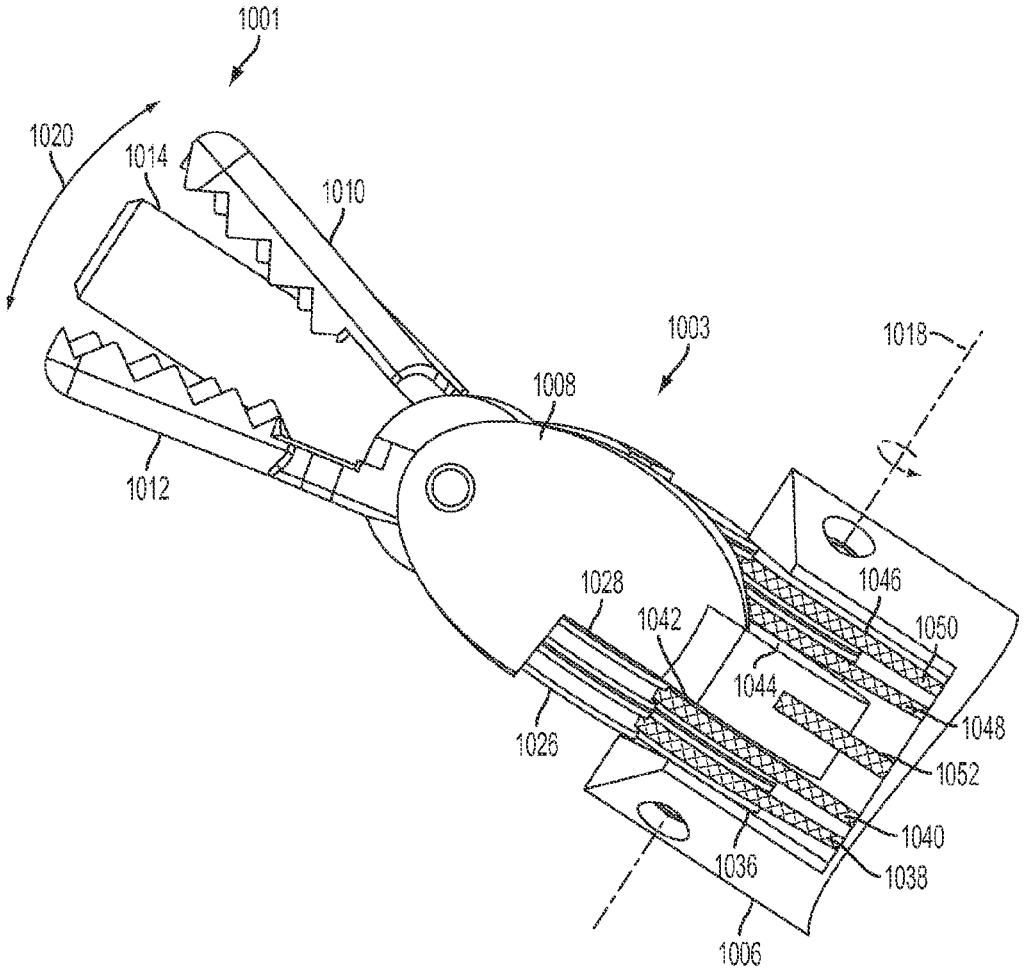

1001
1020
1014
1010
1003
1018
1008
1012
1028
1042
1046
1050
1044
1048
1026
1052
1040
1036
1038
1006

FIG. 44

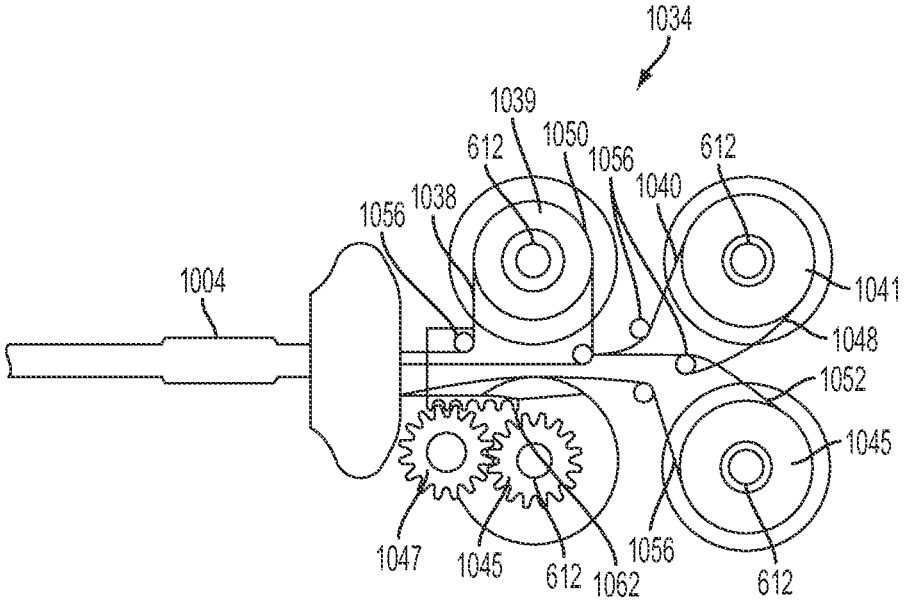



FIG. 45A

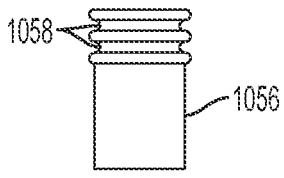



FIG. 45B

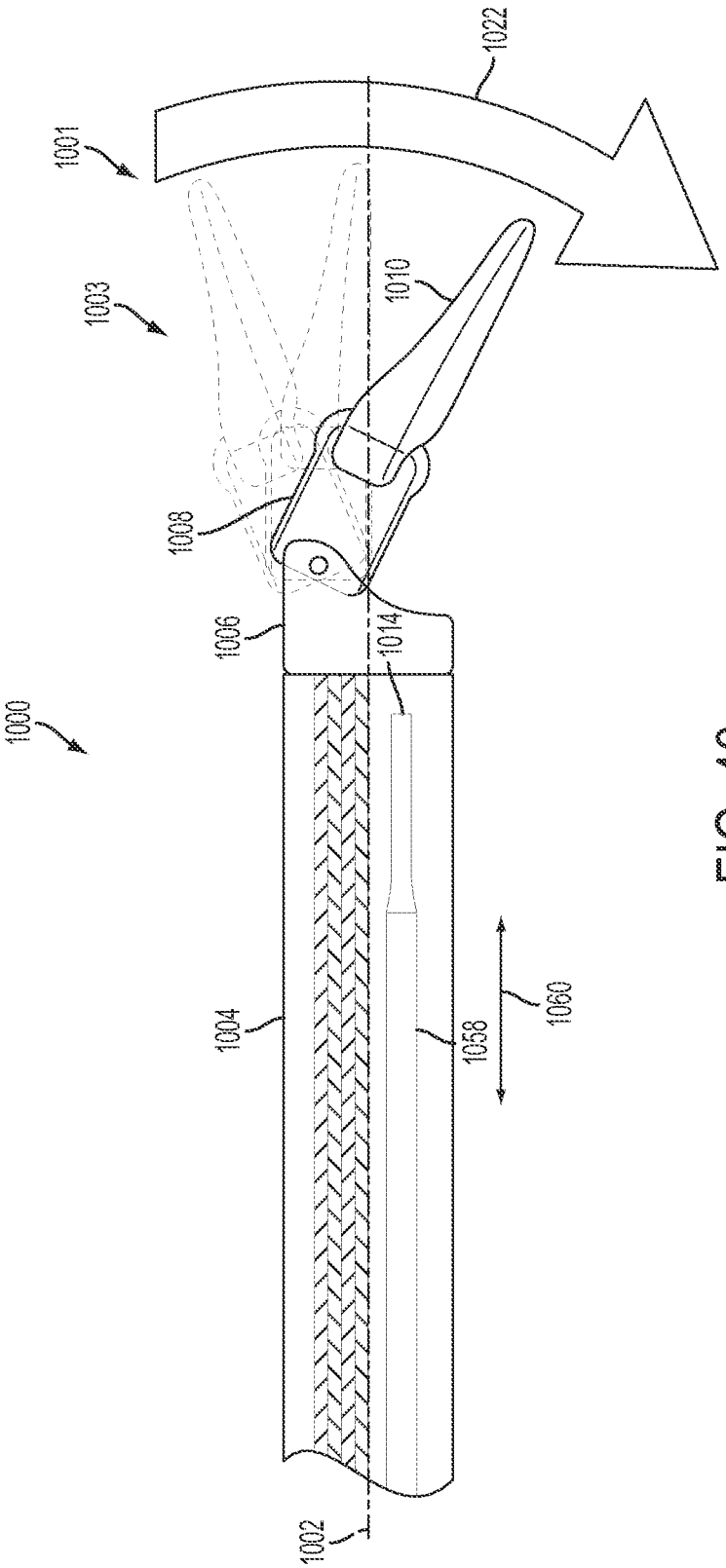



FIG. 46

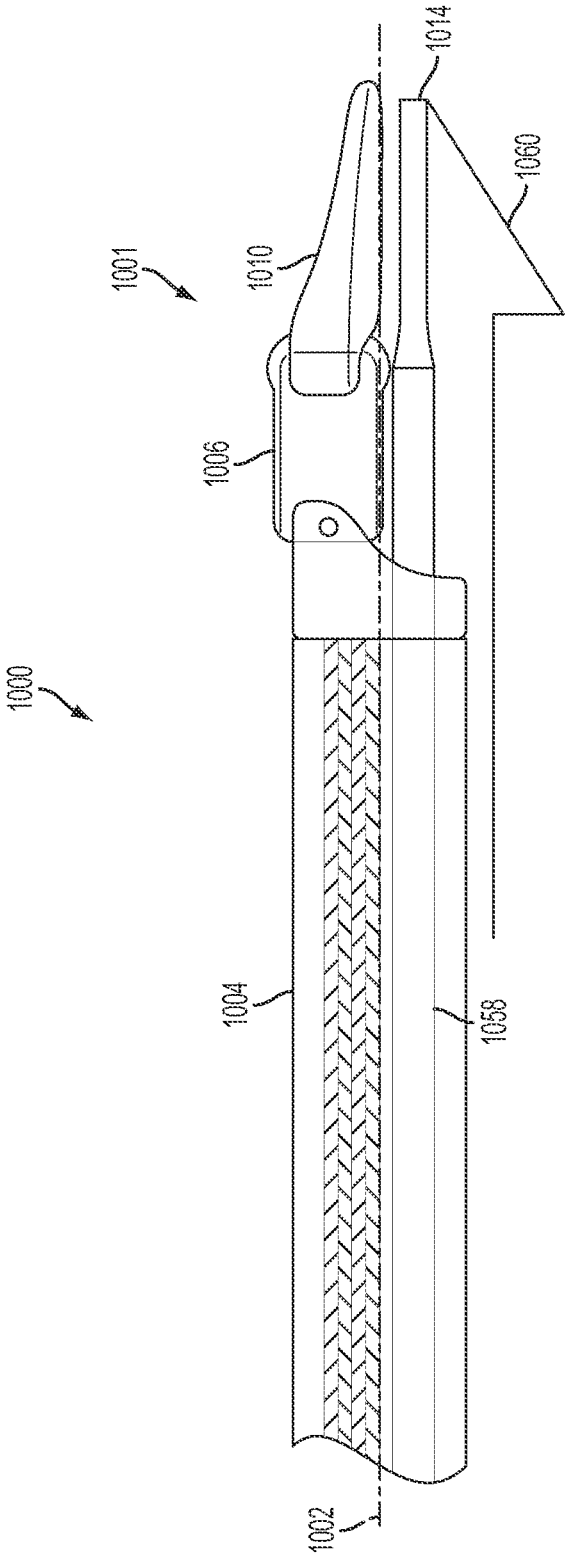
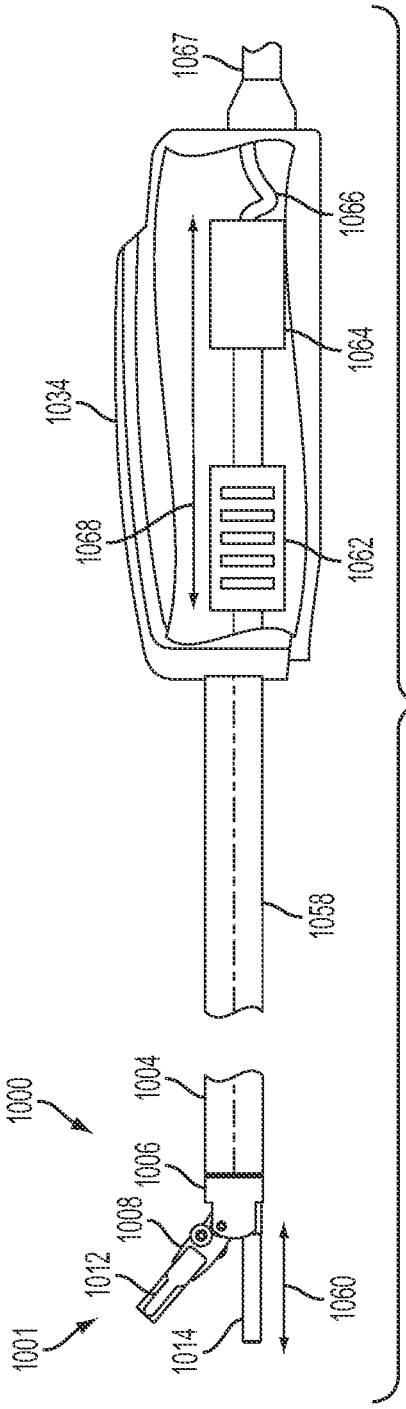



FIG. 47


1067
1066
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1058
1000
1004
1006
1008
1012
1001
1014
1060

FIG. 48

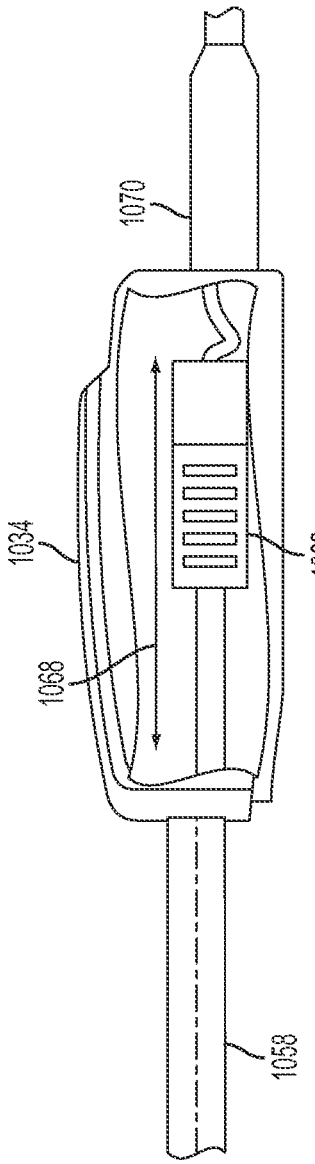


FIG. 49

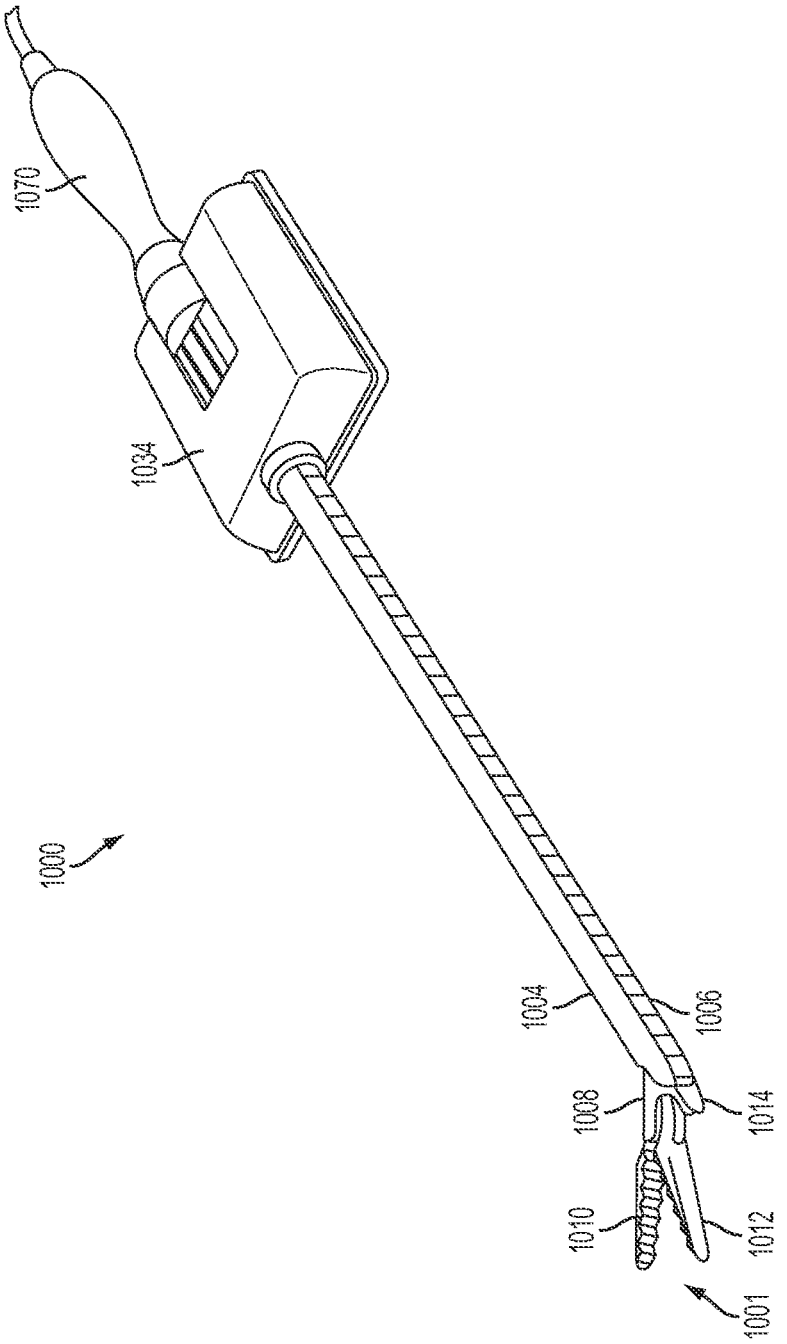


FIG. 50

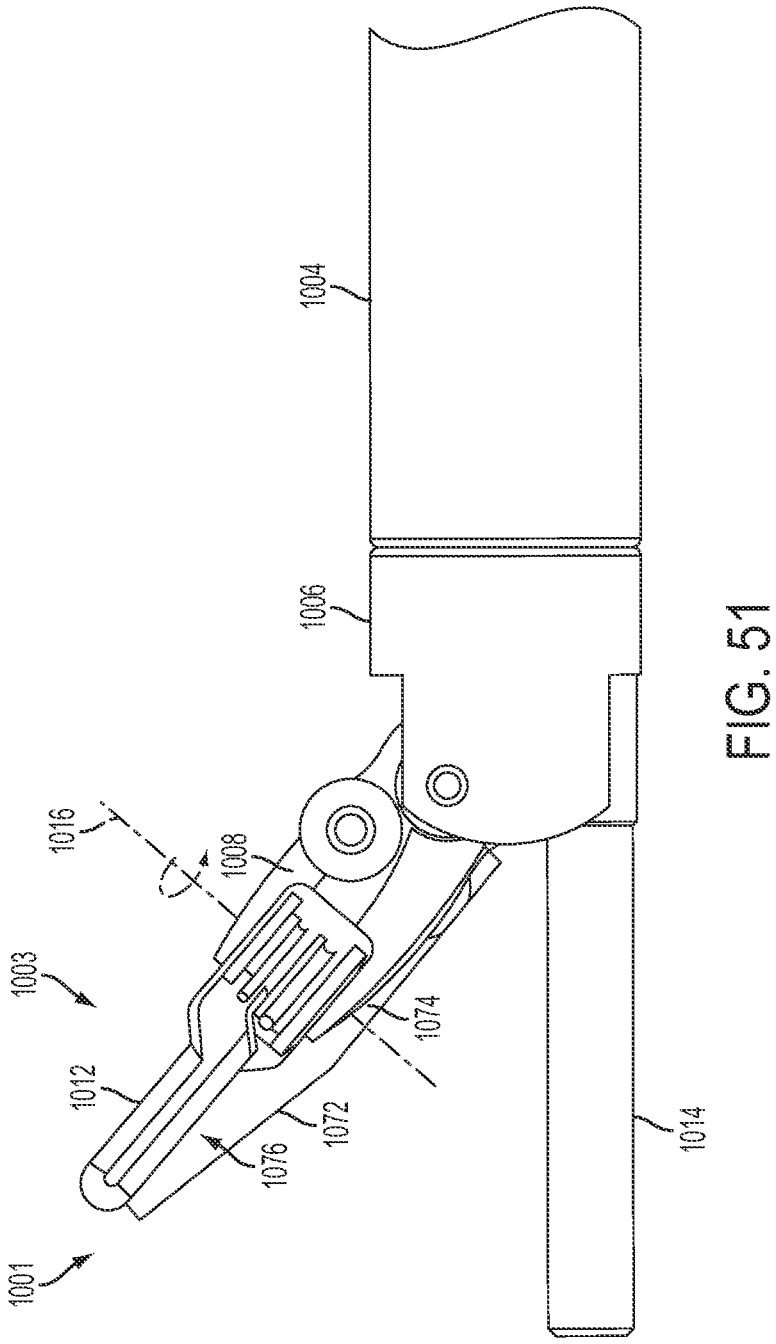


FIG. 51

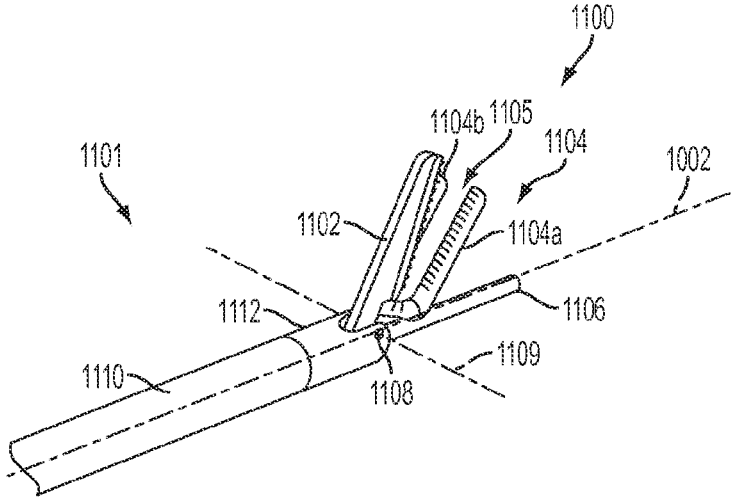


FIG. 52

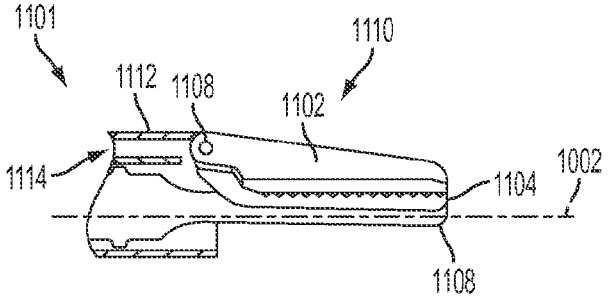


FIG. 53

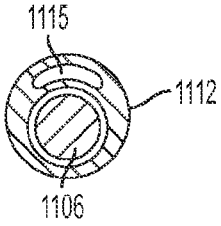


FIG. 54

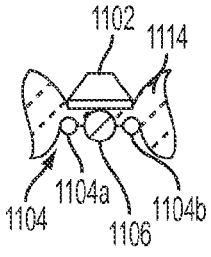


FIG. 55

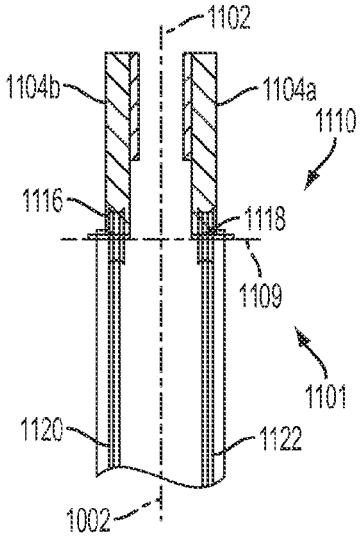


FIG. 56

# ULTRASONIC SURGICAL INSTRUMENTS WITH DISTALLY POSITIONED JAW ASSEMBLIES

## CROSS-REFERENCE TO RELATED APPLICATIONS

The present application is related to the following, concurrently-filed U.S. patent applications, which are incorporated herein by reference in their entirety:

U.S. application Ser. No. 13/539,096, entitled "Haptic Feedback Devices for Surgical Robot," now U.S. Patent Application Publication No. 2014/0005682;

U.S. application Ser. No. 13/539,110, entitled "Lockout Mechanism for Use with Robotic Electrosurgical Device," now U.S. Patent Application Publication No. 2014/0005654;

U.S. application Ser. No. 13/539,117, entitled "Closed Feedback Control for Electrosurgical Device," now U.S. Patent Application Publication No. 2014/0005667;

U.S. application Ser. No. 13/538,588, entitled "Surgical Instruments with Articulating Shafts," now U.S. Patent Application Publication No. 2014/0005701;

U.S. application Ser. No. 13/538,601, entitled "Ultrasonic Surgical Instruments with Distally Positioned Transducers," now U.S. Patent Application Publication No. 2014/0005702;

U.S. application Ser. No. 13/538,700, entitled "Surgical Instruments with Articulating Shafts," now U.S. Patent Application Publication No. 2014/0005703;

U.S. application Ser. No. 13/538,720, entitled "Surgical Instruments with Articulating Shafts," now U.S. Patent Application Publication No. 2014/0005705;

U.S. application Ser. No. 13/538,733, entitled "Ultrasonic Surgical Instruments with Control Mechanisms," now U.S. Patent Application Publication No. 2014/0005681; and

U.S. application Ser. No. 13/539,122, entitled "Surgical Instruments With Fluid Management System," now U.S. Patent Application Publication No. 2014/0005668.

## BACKGROUND

Various embodiments are directed to surgical instruments including ultrasonic instruments distally positioned jaw assemblies.

Ultrasonic surgical devices, such as ultrasonic scalpels, are used in many applications in surgical procedures by virtue of their unique performance characteristics. Depending upon specific device configurations and operational parameters, ultrasonic surgical devices can provide substantially simultaneous transection of tissue and homeostasis by coagulation, desirably minimizing patient trauma. An ultrasonic surgical device comprises a proximally-positioned ultrasonic transducer and an instrument coupled to the ultrasonic transducer having a distally-mounted end effector comprising an ultrasonic blade to cut and seal tissue. The end effector is typically coupled either to a handle and/or a robotic surgical implement via a shaft. The blade is acoustically coupled to the transducer via a waveguide extending through the shaft. Ultrasonic surgical devices of this nature can be configured for open surgical use, laparoscopic, or endoscopic surgical procedures including robotic-assisted procedures.

Ultrasonic energy cuts and coagulates tissue using temperatures lower than those used in electrosurgical procedures. Vibrating at high frequencies (e.g., 55,500 times per second), the ultrasonic blade denatures protein in the tissue to form a sticky coagulum. Pressure exerted on tissue by the blade surface collapses blood vessels and allows the coagulum to form a hemostatic seal. A surgeon can control the cutting



speed and coagulation by the force applied to the tissue by the end effector, the time over which the force is applied and the selected excursion level of the end effector.

It is often desirable for clinicians to articulate a distal portion of the instrument shaft in order to direct the application of ultrasonic and/or RF energy. Such articulation is challenging and often limited in embodiments where an ultrasonic waveguide extends from a proximally-positioned transducer to the distally-positioned ultrasonic blade.

## DRAWINGS

The features of the various embodiments are set forth with particularity in the appended claims. The various embodiments, however, both as to organization and methods of operation, together with advantages thereof, may best be understood by reference to the following description, taken in conjunction with the accompanying drawings as follows:

FIG. **1** illustrates one embodiment of a surgical system including a surgical instrument and an ultrasonic generator.

FIG. **2** illustrates one embodiment of the surgical instrument shown in FIG. **1**.

FIG. **3** illustrates one embodiment of an ultrasonic end effector.

FIG. **4** illustrates another embodiment of an ultrasonic end effector.

FIG. **5** illustrates an exploded view of one embodiment of the surgical instrument shown in FIG. **1**.

FIG. **6** illustrates a cut-away view of one embodiment of the surgical instrument shown in FIG. **1**.

FIG. **7** illustrates various internal components of one embodiment of the surgical instrument shown in FIG. **1**

FIG. **8** illustrates a top view of one embodiment of a surgical system including a surgical instrument and an ultrasonic generator.

FIG. **9** illustrates one embodiment of a rotation assembly included in one example embodiment of the surgical instrument of FIG. **1**.

FIG. **10** illustrates one embodiment of a surgical system including a surgical instrument having a single element end effector.

FIG. **11** illustrates a block diagram of one embodiment of a robotic surgical system.

FIG. **12** illustrates one embodiment of a robotic arm cart.

FIG. **13** illustrates one embodiment of the robotic manipulator of the robotic arm cart of FIG. **12**.

FIG. **14** illustrates one embodiment of a robotic arm cart having an alternative set-up joint structure.

FIG. **15** illustrates one embodiment of a controller that may be used in conjunction with a robotic arm cart, such as the robotic arm carts of FIGS. **11-14**.

FIG. **16** illustrates one embodiment of an ultrasonic surgical instrument adapted for use with a robotic system.

FIG. **25** illustrates one embodiment of an electrosurgical instrument adapted for use with a robotic system.

FIG. **17** illustrates one embodiment of an instrument drive assembly that may be coupled to a surgical manipulators to receive and control the surgical instrument shown in FIG. **16**.

FIG. **18** illustrates another view of the instrument drive assembly embodiment of FIG. **26** including the surgical instrument of FIG. **16**.

FIGS. **19-21** illustrate additional views of the adapter portion of the instrument drive assembly embodiment of FIG. **26**.

FIGS. **22-24** illustrate one embodiment of the instrument mounting portion of FIG. **16** showing components for translating motion of the driven elements into motion of the surgical instrument.

FIGS. **25-27** illustrate an alternate embodiment of the instrument mounting portion of FIG. **16** showing an alternate example mechanism for translating rotation of the driven elements into rotational motion about the axis of the shaft and an alternate example mechanism for generating reciprocating translation of one or more members along the axis of the shaft.

FIGS. **28-32** illustrate an alternate embodiment of the instrument mounting portion FIG. **16** showing another alternate example mechanism for translating rotation of the driven elements into rotational motion about the axis of the shaft.

FIGS. **33-36**A illustrate an alternate embodiment of the instrument mounting portion showing an alternate example mechanism for differential translation of members along the axis of the shaft (e.g., for articulation).

FIGS. **36**B-**36**C illustrate one embodiment of a tool mounting portion comprising internal power and energy sources.

FIGS. **37-38** illustrates one embodiment of a distal portion of a surgical instrument comprising a distally positioned jaw assembly.

FIG. **39** illustrates a head-on view of one embodiment of the distal portion of the surgical instrument of FIGS. **37-38**.

FIGS. **40-41** illustrate one embodiment of the distal portion of the surgical instrument of FIGS. **37-38** coupled to an instrument mounting portion for use with a robotic surgical system.

FIGS. **42-44** illustrate one embodiment of the distal portion of the surgical instrument of FIGS. **37-38** showing additional control mechanisms.

FIG. **45**A illustrates one embodiment of the instrument mounting portion showing an example mechanism for actuating various control lines of the surgical instrument of FIGS. **37-38**.

FIG. **45**B illustrates a side view of one embodiment of the routers.

FIGS. **46-47** illustrate one embodiment of the distal portion of the surgical instrument of FIGS. **37-38** with a retractable ultrasonic blade.

FIG. **48** illustrates one embodiment of the distal portion of the surgical instrument of FIGS. **37-38** coupled to an instrument mounting portion of a robotic surgical system configured to extend and retract the ultrasonic blade.

FIG. **49** illustrates an alternate embodiment of the distal portion of the surgical instrument of FIGS. **37-38** coupled to an instrument mounting portion of a robotic surgical system with an external transducer.

FIG. **50** illustrates an additional view of the distal portion of the surgical instrument of FIGS. **37-38** as illustrated in FIG. **49**.

FIG. **51** illustrates one embodiment of the jaw assembly comprising a clamp pad.

FIGS. **52-56** illustrate one embodiment of a distal portion of a surgical instrument comprising a jaw assembly with a U-shaped jaw member.

## DESCRIPTION

Various embodiments described herein are directed to surgical instruments comprising distally positioned, articulatable jaw assemblies. The jaw assemblies may be utilized in lieu of or in addition to shaft articulation. For example, the jaw assemblies may be utilized to grasp tissue and move it towards an ultrasonic blade, RF electrodes or other component for treating tissue.

According to one example embodiments, a surgical instrument may comprise an end effector with an ultrasonic blade extending distally therefrom. The jaw assembly may be articulatable and may pivot about at least two axes. A first axis, or wrist pivot axis, may be substantially perpendicular to a longitudinal axis of the instrument shaft. The jaw assembly may pivot about the wrist pivot axis from a first position where the jaw assembly is substantially parallel to the ultrasonic blade to a second position where the jaw assembly is not substantially parallel to the ultrasonic blade. In addition, the jaw assembly may comprise first and second jaw members that are pivotable about a second axis or jaw pivot axis. The jaw pivot axis may be substantially perpendicular to the wrist pivot axis. In some embodiments, the jaw pivot axis itself may pivot as the jaw assembly pivots about the wrist pivot axis. The first and second jaw members may be pivotably relative to one another about the jaw pivot axis such that the first and second jaw members may "open" and "close." Additionally, in some embodiments, the first and second jaw members are also pivotable about the jaw pivot axis together such that the direction of the first and second jaw members may change.

In various embodiments, the jaw assembly is controlled by a series of lines and/or cables that extend proximally from the jaw assembly to a manual handle and/or instrument mounting portion of a robotic surgical system. First and second lines may control pivoting of the jaw assembly about the wrist pivot axis. A first line may be coupled to the jaw assembly at a position offset from the wrist pivot axis. A second line may be coupled to the jaw assembly at a second position offset from the wrist pivot axis and substantially opposite the first position. Differential translation of the first and second lines may cause pivoting of the jaw assembly about the wrist pivot axis. For example, proximal translation of one of the lines may cause the jaw assembly to pivot away from the longitudinal axis of the shaft towards the proximally translated line. In some embodiments, the jaw assembly may comprise a pulley positioned about the wrist pivot axis. The first and second lines may be first and second ends of a single line wrapped around the pulley.

The first and second jaw members may be similarly controlled. For example, in some embodiments, each jaw member is coupled to two control lines that extend proximally from the jaw assembly through the shaft to the manual handle and/or instrument mounting portion of the robotic surgical system. The control lines for each jaw member may be offset from one another about the jaw pivot axis such that proximal translation of one control line pivots the jaw about the jaw pivot axis in a first direction and proximal translation of the other control line pivots the jaw about the jaw pivot axis in a second direction opposite the first. In some embodiments the first and second jaw members comprise pulleys positioned about the jaw pivot axis and the first and second control lines for each jaw member are ends of a single control line wrapped around the respective pulleys. In some embodiments, the jaw members are separately controllable. For example, the jaw members may open and close about the jaw pivot axis and may additional pivot together about the jaw pivot axis.

Reference will now be made in detail to several embodiments, including embodiments showing example implementations of manual and robotic surgical instruments with end effectors comprising ultrasonic and/or electrosurgical elements. Wherever practicable similar or like reference numbers may be used in the figures and may indicate similar or like functionality. The figures depict example embodiments of the disclosed surgical instruments and/or methods of use for purposes of illustration only. One skilled in the art will readily recognize from the following description that alternative example embodiments of the structures and methods illustrated herein may be employed without departing from the principles described herein.

FIG. **1** is a right side view of one embodiment of an ultrasonic surgical instrument **10**. In the illustrated embodiment, the ultrasonic surgical instrument **10** may be employed in various surgical procedures including endoscopic or traditional open surgical procedures. In one example embodiment, the ultrasonic surgical instrument **10** comprises a handle assembly **12**, an elongated shaft assembly **14**, and an ultrasonic transducer **16**. The handle assembly **12** comprises a trigger assembly **24**, a distal rotation assembly **13**, and a switch assembly **28**. The elongated shaft assembly **14** comprises an end effector assembly **26**, which comprises elements to dissect tissue or mutually grasp, cut, and coagulate vessels and/or tissue, and actuating elements to actuate the end effector assembly **26**. The handle assembly **12** is adapted to receive the ultrasonic transducer **16** at the proximal end. The ultrasonic transducer **16** is mechanically engaged to the elongated shaft assembly **14** and portions of the end effector assembly **26**. The ultrasonic transducer **16** is electrically coupled to a generator **20** via a cable **22**. Although the majority of the drawings depict a multiple end effector assembly **26** for use in connection with laparoscopic surgical procedures, the ultrasonic surgical instrument **10** may be employed in more traditional open surgical procedures and in other embodiments, may be configured for use in endoscopic procedures. For the purposes herein, the ultrasonic surgical instrument **10** is described in terms of an endoscopic instrument; however, it is contemplated that an open and/or laparoscopic version of the ultrasonic surgical instrument **10** also may include the same or similar operating components and features as described herein.

In various embodiments, the generator **20** comprises several functional elements, such as modules and/or blocks. Different functional elements or modules may be configured for driving different kinds of surgical devices. For example, an ultrasonic generator module **21** may drive an ultrasonic device, such as the ultrasonic surgical instrument **10**. In some example embodiments, the generator **20** also comprises an electrosurgery/RF generator module **23** for driving an electrosurgical device (or an electrosurgical embodiment of the ultrasonic surgical instrument **10**). In the example embodiment illustrated in FIG. **1**, the generator **20** includes a control system **25** integral with the generator **20**, and a foot switch **29** connected to the generator via a cable **27**. The generator **20** may also comprise a triggering mechanism for activating a surgical instrument, such as the instrument **10**. The triggering mechanism may include a power switch (not shown) as well as a foot switch **29**. When activated by the foot switch **29**, the generator **20** may provide energy to drive the acoustic assembly of the surgical instrument **10** and to drive the end effector **18** at a predetermined excursion level. The generator **20** drives or excites the acoustic assembly at any suitable resonant frequency of the acoustic assembly and/or derives the therapeutic/sub-therapeutic electromagnetic/RF energy. As shown in FIG. **1**, according to various embodiments, the ultrasonic generator module **21** and/or the electrosurgery/RF generator module **23** may be located external to the generator (shown in phantom as ultrasonic generator module **21'** and electrosurgery/RF generator module **23'**).

In one embodiment, the electrosurgical/RF generator module **23** may be implemented as an electrosurgery unit (ESU) capable of supplying power sufficient to perform bipolar electrosurgery using radio frequency (RF) energy. In one embodiment, the ESU can be a bipolar ERBE ICC 350 sold by ERBE USA, Inc. of Marietta, Ga. In bipolar electrosurgery applications, as previously discussed, a surgical instrument having an active electrode and a return electrode can be utilized, wherein the active electrode and the return electrode can be positioned against, or adjacent to, the tissue to be treated such that current can flow from the active electrode to the return electrode through the tissue. Accordingly, the electrosurgical/RF module **23** generator may be configured for therapeutic purposes by applying electrical energy to the tissue T sufficient for treating the tissue (e.g., cauterization). For example, in some embodiments, the active and/or return electrode may be positioned on the jaw assembly described herein.

In one embodiment, the electrosurgical/RF generator module **23** may be configured to deliver a subtherapeutic RF signal to implement a tissue impedance measurement module. In one embodiment, the electrosurgical/RF generator module **23** comprises a bipolar radio frequency generator as described in more detail below. In one embodiment, the electrosurgical/RF generator module **23** may be configured to monitor electrical impedance Z, of tissue T and to control the characteristics of time and power level based on the tissue T by way of a return electrode provided on a clamp member of the end effector assembly **26**. Accordingly, the electrosurgical/RF generator module **23** may be configured for subtherapeutic purposes for measuring the impedance or other electrical characteristics of the tissue T. Techniques and circuit configurations for measuring the impedance or other electrical characteristics of tissue T are discussed in more detail in commonly assigned U.S. Patent Publication No. 2011/0015631, titled "Electrosurgical Generator for Ultrasonic Surgical Instruments," the disclosure of which is herein incorporated by reference in its entirety.

A suitable ultrasonic generator module **21** may be configured to functionally operate in a manner similar to the GEN300 sold by Ethicon Endo-Surgery, Inc. of Cincinnati, Ohio as is disclosed in one or more of the following U.S. patents, all of which are incorporated by reference herein: U.S. Pat. No. 6,480,796 (Method for Improving the Start Up of an Ultrasonic System Under Zero Load Conditions); U.S. Pat. No. 6,537,291 (Method for Detecting Blade Breakage Using Rate and/or Impedance Information); U.S. Pat. No. 6,662,127 (Method for Detecting Presence of a Blade in an Ultrasonic System); U.S. Pat. No. 6,977,495 (Detection Circuitry for Surgical Handpiece System); U.S. Pat. No. 7,077,853 (Method for Calculating Transducer Capacitance to Determine Transducer Temperature); U.S. Pat. No. 7,179,271 (Method for Driving an Ultrasonic System to Improve Acquisition of Blade Resonance Frequency at Startup); and U.S. Pat. No. 7,273,483 (Apparatus and Method for Alerting Generator Function in an Ultrasonic Surgical System).

It will be appreciated that in various embodiments, the generator **20** may be configured to operate in several modes. In one mode, the generator **20** may be configured such that the ultrasonic generator module **21** and the electrosurgical/RF generator module **23** may be operated independently.

For example, the ultrasonic generator module **21** may be activated to apply ultrasonic energy to the end effector assembly **26** and subsequently, either therapeutic or sub-therapeutic RF energy may be applied to the end effector assembly **26** by the electrosurgical/RF generator module **23**. As previously discussed, the sub-therapeutic electrosurgical/RF energy may be applied to tissue clamped between claim elements of the end effector assembly **26** to measure tissue impedance to control the activation, or modify the activation, of the ultrasonic generator module **21**. Tissue impedance feedback from the application of the sub-therapeutic energy also may be employed to activate a therapeutic level of the electrosurgical/RF generator module **23** to seal the tissue (e.g., vessel) clamped between claim elements of the end effector assembly **26**.

In another embodiment, the ultrasonic generator module **21** and the electrosurgical/RF generator module **23** may be activated simultaneously. In one example, the ultrasonic generator module **21** is simultaneously activated with a sub-therapeutic RF energy level to measure tissue impedance simultaneously while the ultrasonic blade of the end effector assembly **26** cuts and coagulates the tissue (or vessel) clamped between the clamp elements of the end effector assembly **26**. Such feedback may be employed, for example, to modify the drive output of the ultrasonic generator module **21**. In another example, the ultrasonic generator module **21** may be driven simultaneously with electrosurgical/RF generator module **23** such that the ultrasonic blade portion of the end effector assembly **26** is employed for cutting the damaged tissue while the electrosurgical/RF energy is applied to electrode portions of the end effector clamp assembly **26** for sealing the tissue (or vessel).

When the generator **20** is activated via the triggering mechanism, electrical energy is continuously applied by the generator **20** to a transducer stack or assembly of the acoustic assembly. In another embodiment, electrical energy is intermittently applied (e.g., pulsed) by the generator **20**. A phase-locked loop in the control system of the generator **20** may monitor feedback from the acoustic assembly. The phase lock loop adjusts the frequency of the electrical energy sent by the generator **20** to match the resonant frequency of the selected longitudinal mode of vibration of the acoustic assembly. In addition, a second feedback loop in the control system **25** maintains the electrical current supplied to the acoustic assembly at a pre-selected constant level in order to achieve substantially constant excursion at the end effector **18** of the acoustic assembly. In yet another embodiment, a third feedback loop in the control system **25** monitors impedance between electrodes located in the end effector assembly **26**. Although FIGS. **1-9** show a manually operated ultrasonic surgical instrument, it will be appreciated that ultrasonic surgical instruments may also be used in robotic applications, for example, as described herein as well as combinations of manual and robotic applications.

In ultrasonic operation mode, the electrical signal supplied to the acoustic assembly may cause the distal end of the end effector **18**, to vibrate longitudinally in the range of, for example, approximately 20 kHz to 250 kHz. According to various embodiments, the blade **22** may vibrate in the range of about 54 kHz to 56 kHz, for example, at about 55.5 kHz. In other embodiments, the blade **22** may vibrate at other frequencies including, for example, about 31 kHz or about 80 kHz. The excursion of the vibrations at the blade can be controlled by, for example, controlling the amplitude of the electrical signal applied to the transducer assembly of the acoustic assembly by the generator **20**. As noted above, the triggering mechanism of the generator **20** allows a user to activate the generator **20** so that electrical energy may be continuously or intermittently supplied to the acoustic assembly. The generator **20** also has a power line for insertion in an electro-surgical unit or conventional electrical outlet. It is contemplated that the generator **20** can also be powered by a direct current (DC) source, such as a battery. The generator **20** can comprise any suitable generator, such as Model No. GEN04, and/or Model No. GEN11 available from Ethicon Endo-Surgery, Inc.

FIG. **2** is a left perspective view of one example embodiment of the ultrasonic surgical instrument **10** showing the handle assembly **12**, the distal rotation assembly **13**, the elongated shaft assembly **14**, and the end effector assembly **26**. In the illustrated embodiment the elongated shaft assembly **14** comprises a distal end **52** dimensioned to mechanically engage the end effector assembly **26** and a proximal end **50** that mechanically engages the handle assembly **12** and the distal rotation assembly **13**. The proximal end **50** of the elongated shaft assembly **14** is received within the handle assembly **12** and the distal rotation assembly **13**. More details relating to the connections between the elongated shaft assembly **14**, the handle assembly **12**, and the distal rotation assembly **13** are provided in the description of FIGS. **5** and **7**.

In the illustrated embodiment, the trigger assembly **24** comprises a trigger **32** that operates in conjunction with a fixed handle **34**. The fixed handle **34** and the trigger **32** are ergonomically formed and adapted to interface comfortably with the user. The fixed handle **34** is integrally associated with the handle assembly **12**. The trigger **32** is pivotally movable relative to the fixed handle **34** as explained in more detail below with respect to the operation of the ultrasonic surgical instrument **10**. The trigger **32** is pivotally movable in direction **33**A toward the fixed handle **34** when the user applies a squeezing force against the trigger **32**. A spring element **98** (FIG. **5**) causes the trigger **32** to pivotally move in direction **33**B when the user releases the squeezing force against the trigger **32**.

In one example embodiment, the trigger **32** comprises an elongated trigger hook **36**, which defines an aperture **38** between the elongated trigger hook **36** and the trigger **32**. The aperture **38** is suitably sized to receive one or multiple fingers of the user therethrough. The trigger **32** also may comprise a resilient portion **32***a* molded over the trigger **32** substrate. The resilient portion **32***a* is formed to provide a more comfortable contact surface for control of the trigger **32** in outward direction **33**B. In one example embodiment, the resilient portion **32***a* may also be provided over a portion of the elongated trigger hook **36** as shown, for example, in FIG. **2**. The proximal surface of the elongated trigger hook **32** remains uncoated or coated with a non-resilient substrate to enable the user to easily slide their fingers in and out of the aperture **38**. In another embodiment, the geometry of the trigger forms a fully closed loop which defines an aperture suitably sized to receive one or multiple fingers of the user therethrough. The fully closed loop trigger also may comprise a resilient portion molded over the trigger substrate.

In one example embodiment, the fixed handle **34** comprises a proximal contact surface **40** and a grip anchor or saddle surface **42**. The saddle surface **42** rests on the web where the thumb and the index finger are joined on the hand. The proximal contact surface **40** has a pistol grip contour that receives the palm of the hand in a normal pistol grip with no rings or apertures. The profile curve of the proximal contact surface **40** may be contoured to accommodate or receive the palm of the hand. A stabilization tail **44** is located towards a more proximal portion of the handle assembly **12**. The stabilization tail **44** may be in contact with the uppermost web portion of the hand located between the thumb and the index finger to stabilize the handle assembly **12** and make the handle assembly **12** more controllable.

In one example embodiment, the switch assembly **28** may comprise a toggle switch **30**. The toggle switch **30** may be implemented as a single component with a central pivot **304** located within inside the handle assembly **12** to eliminate the possibility of simultaneous activation. In one example embodiment, the toggle switch **30** comprises a first projecting knob **30***a* and a second projecting knob **30***b* to set the power setting of the ultrasonic transducer **16** between a minimum power level (e.g., MIN) and a maximum power level (e.g., MAX). In another embodiment, the rocker switch may pivot between a standard setting and a special setting. The special setting may allow one or more special programs to be imple-

mented by the device. The toggle switch **30** rotates about the central pivot as the first projecting knob **30***a* and the second projecting knob **30***b* are actuated. The one or more projecting knobs **30***a*, **30***b* are coupled to one or more arms that move through a small arc and cause electrical contacts to close or open an electric circuit to electrically energize or de-energize the ultrasonic transducer **16** in accordance with the activation of the first or second projecting knobs **30***a*, **30***b*. The toggle switch **30** is coupled to the generator **20** to control the activation of the ultrasonic transducer **16**. The toggle switch **30** comprises one or more electrical power setting switches to activate the ultrasonic transducer **16** to set one or more power settings for the ultrasonic transducer **16**. The forces required to activate the toggle switch **30** are directed substantially toward the saddle point **42**, thus avoiding any tendency of the instrument to rotate in the hand when the toggle switch **30** is activated.

In one example embodiment, the first and second projecting knobs **30***a*, **30***b* are located on the distal end of the handle assembly **12** such that they can be easily accessible by the user to activate the power with minimal, or substantially no, repositioning of the hand grip, making it suitable to maintain control and keep attention focused on the surgical site (e.g., a monitor in a laparoscopic procedure) while activating the toggle switch **30**. The projecting knobs **30***a*, **30***b* may be configured to wrap around the side of the handle assembly **12** to some extent to be more easily accessible by variable finger lengths and to allow greater freedom of access to activation in awkward positions or for shorter fingers.

In the illustrated embodiment, the first projecting knob **30***a* comprises a plurality of tactile elements **30***c*, e.g., textured projections or "bumps" in the illustrated embodiment, to allow the user to differentiate the first projecting knob **30***a* from the second projecting knob **30***b*. It will be appreciated by those skilled in the art that several ergonomic features may be incorporated into the handle assembly **12**. Such ergonomic features are described in U.S. Pat. App. Pub. No. 2009/0105750 entitled "Ergonomic Surgical Instruments", now U.S. Pat. No. 8,623,027, which is incorporated by reference herein in its entirety.

In one example embodiment, the toggle switch **30** may be operated by the hand of the user. The user may easily access the first and second projecting knobs **30***a*, **30***b* at any point while also avoiding inadvertent or unintentional activation at any time. The toggle switch **30** may readily operated with a finger to control the power to the ultrasonic assembly **16** and/or to the ultrasonic assembly **16**. For example, the index finger may be employed to activate the first contact portion **30***a* to turn on the ultrasonic assembly **16** to a maximum (MAX) power level. The index finger may be employed to activate the second contact portion **30***b* to turn on the ultrasonic assembly **16** to a minimum (MIN) power level. In another embodiment, the rocker switch may pivot the instrument **10** between a standard setting and a special setting. The special setting may allow one or more special programs to be implemented by the instrument **10**. The toggle switch **30** may be operated without the user having to look at the first or second projecting knob **30***a*, **30***b*. For example, the first projecting knob **30***a* or the second projecting knob **30***b* may comprise a texture or projections to tactilely differentiate between the first and second projecting knobs **30***a*, **30***b* without looking

In one example embodiment, the distal rotation assembly **13** is rotatable without limitation in either direction about a longitudinal axis "T." The distal rotation assembly **13** is mechanically engaged to the elongated shaft assembly **14**. The distal rotation assembly **13** is located on a distal end of the handle assembly **12**. The distal rotation assembly **13** comprises a cylindrical hub **46** and a rotation knob **48** formed over the hub **46**. The hub **46** mechanically engages the elongated shaft assembly **14**. The rotation knob **48** may comprise fluted polymeric features and may be engaged by a finger (e.g., an index finger) to rotate the elongated shaft assembly **14**. The hub **46** may comprise a material molded over the primary structure to form the rotation knob **48**. The rotation knob **48** may be overmolded over the hub **46**. The hub **46** comprises an end cap portion **46***a* that is exposed at the distal end. The end cap portion **46***a* of the hub **46** may contact the surface of a trocar during laparoscopic procedures. The hub **46** may be formed of a hard durable plastic such as polycarbonate to alleviate any friction that may occur between the end cap portion **46***a* and the trocar. The rotation knob **48** may comprise "scallops" or flutes formed of raised ribs **48***a* and concave portions **48***b* located between the ribs **48***a* to provide a more precise rotational grip. In one example embodiment, the rotation knob **48** may comprise a plurality of flutes (e.g., three or more flutes). In other embodiments, any suitable number of flutes may be employed. The rotation knob **48** may be formed of a softer polymeric material overmolded onto the hard plastic material. For example, the rotation knob **48** may be formed of pliable, resilient, flexible polymeric materials including Versaflex® TPE alloys made by GLS Corporation, for example. This softer overmolded material may provide a greater grip and more precise control of the movement of the rotation knob **48**. It will be appreciated that any materials that provide adequate resistance to sterilization, are biocompatible, and provide adequate frictional resistance to surgical gloves may be employed to form the rotation knob **48**.

In one example embodiment, the handle assembly **12** is formed from two (2) housing portions or shrouds comprising a first portion **12***a* and a second portion **12***b*. From the perspective of a user viewing the handle assembly **12** from the distal end towards the proximal end, the first portion **12***a* is considered the right portion and the second portion **12***b* is considered the left portion. Each of the first and second portions **12***a*, **12***b* includes a plurality of interfaces **69** (FIG. **7**) dimensioned to mechanically align and engage each another to form the handle assembly **12** and enclosing the internal working components thereof. The fixed handle **34**, which is integrally associated with the handle assembly **12**, takes shape upon the assembly of the first and second portions **12***a* and **12***b* of the handle assembly **12**. A plurality of additional interfaces (not shown) may be disposed at various points around the periphery of the first and second portions **12***a* and **12***b* of the handle assembly **12** for ultrasonic welding purposes, e.g., energy direction/deflection points. The first and second portions **12***a* and **12***b* (as well as the other components described below) may be assembled together in any fashion known in the art. For example, alignment pins, snap-like interfaces, tongue and groove interfaces, locking tabs, adhesive ports, may all be utilized either alone or in combination for assembly purposes.

In one example embodiment, the elongated shaft assembly **14** comprises a proximal end **50** adapted to mechanically engage the handle assembly **12** and the distal rotation assembly **13**; and a distal end **52** adapted to mechanically engage the end effector assembly **26**. The elongated shaft assembly **14** comprises an outer tubular sheath **56** and a reciprocating tubular actuating member **58** located within the outer tubular sheath **56**. The proximal end of the tubular reciprocating tubular actuating member **58** is mechanically engaged to the trigger **32** of the handle assembly **12** to move in either direction **60**A or **60**B in response to the actuation and/or release of the trigger **32**. The pivotably moveable trigger **32** may gen-

erate reciprocating motion along the longitudinal axis "T." Such motion may be used, for example, to actuate the jaws or clamping mechanism of the end effector assembly **26**. A series of linkages translate the pivotal rotation of the trigger **32** to axial movement of a yoke coupled to an actuation mechanism, which controls the opening and closing of the jaws of the clamping mechanism of the end effector assembly **26**. The distal end of the tubular reciprocating tubular actuating member **58** is mechanically engaged to the end effector assembly **26**. In the illustrated embodiment, the distal end of the tubular reciprocating tubular actuating member **58** is mechanically engaged to a clamp arm assembly **64**, which is pivotable about a pivot point **70**, to open and close the clamp arm assembly **64** in response to the actuation and/or release of the trigger **32**. For example, in the illustrated embodiment, the clamp arm assembly **64** is movable in direction **62**A from an open position to a closed position about a pivot point **70** when the trigger **32** is squeezed in direction **33**A. The clamp arm assembly **64** is movable in direction **62**B from a closed position to an open position about the pivot point **70** when the trigger **32** is released or outwardly contacted in direction **33**B.

In one example embodiment, the end effector assembly **26** is attached at the distal end **52** of the elongated shaft assembly **14** and includes a clamp arm assembly **64** and a blade **66**. The jaws of the clamping mechanism of the end effector assembly **26** are formed by clamp arm assembly **64** and the blade **66**. The blade **66** is ultrasonically actuatable and is acoustically coupled to the ultrasonic transducer **16**. The trigger **32** on the handle assembly **12** is ultimately connected to a drive assembly, which together, mechanically cooperate to effect movement of the clamp arm assembly **64**. Squeezing the trigger **32** in direction **33**A moves the clamp arm assembly **64** in direction **62**A from an open position, wherein the clamp arm assembly **64** and the blade **66** are disposed in a spaced relation relative to one another, to a clamped or closed position, wherein the clamp arm assembly **64** and the blade **66** cooperate to grasp tissue therebetween. The clamp arm assembly **64** may comprise a clamp pad (not shown) to engage tissue between the blade **66** and the clamp arm **64**. Releasing the trigger **32** in direction **33**B moves the clamp arm assembly **64** in direction **62**B from a closed relationship, to an open position, wherein the clamp arm assembly **64** and the blade **66** are disposed in a spaced relation relative to one another.

The proximal portion of the handle assembly **12** comprises a proximal opening **68** to receive the distal end of the ultrasonic assembly **16**. The ultrasonic assembly **16** is inserted in the proximal opening **68** and is mechanically engaged to the elongated shaft assembly **14**.

In one example embodiment, the elongated trigger hook **36** portion of the trigger **32** provides a longer trigger lever with a shorter span and rotation travel. The longer lever of the elongated trigger hook **36** allows the user to employ multiple fingers within the aperture **38** to operate the elongated trigger hook **36** and cause the trigger **32** to pivot in direction **33**B to open the jaws of the end effector assembly **26**. For example, the user may insert three fingers (e.g., the middle, ring, and little fingers) in the aperture **38**. Multiple fingers allows the surgeon to exert higher input forces on the trigger **32** and the elongated trigger hook **326** to activate the end effector assembly **26**. The shorter span and rotation travel creates a more comfortable grip when closing or squeezing the trigger **32** in direction **33**A or when opening the trigger **32** in the outward opening motion in direction **33**B lessening the need to extend the fingers further outward. This substantially lessens hand fatigue and strain associated with the outward opening motion of the trigger **32** in direction **33**B. The outward opening motion of the trigger may be spring-assisted by spring element **98** (FIG. **5**) to help alleviate fatigue. The opening spring force is sufficient to assist the ease of opening, but not strong enough to adversely impact the tactile feedback of tissue tension during spreading dissection.

For example, during a surgical procedure the index finger may be used to control the rotation of the elongated shaft assembly **14** to locate the jaws of the end effector assembly **26** in a suitable orientation. The middle and/or the other lower fingers may be used to squeeze the trigger **32** and grasp tissue within the jaws. Once the jaws are located in the desired position and the jaws are clamped against the tissue, the index finger can be used to activate the toggle switch **30** to adjust the power level of the ultrasonic transducer **16** to treat the tissue. Once the tissue has been treated, the user may release the trigger **32** by pushing outwardly in the distal direction against the elongated trigger hook **36** with the middle and/or lower fingers to open the jaws of the end effector assembly **26**. This basic procedure may be performed without the user having to adjust their grip of the handle assembly **12**.

FIGS. **3-4** illustrate the connection of the elongated shaft assembly **14** relative to the end effector assembly **26**. As previously described, in the illustrated embodiment, the end effector assembly **26** comprises a clamp arm assembly **64** and a blade **66** to form the jaws of the clamping mechanism. The blade **66** may be an ultrasonically actuatable blade acoustically coupled to the ultrasonic transducer **16**. The trigger **32** is mechanically connected to a drive assembly. Together, the trigger **32** and the drive assembly mechanically cooperate to move the clamp arm assembly **64** to an open position in direction **62**A wherein the clamp arm assembly **64** and the blade **66** are disposed in spaced relation relative to one another, to a clamped or closed position in direction **62**B wherein the clamp arm assembly **64** and the blade **66** cooperate to grasp tissue therebetween. The clamp arm assembly **64** may comprise a clamp pad (not shown) to engage tissue between the blade **66** and the clamp arm **64**. The distal end of the tubular reciprocating tubular actuating member **58** is mechanically engaged to the end effector assembly **26**. In the illustrated embodiment, the distal end of the tubular reciprocating tubular actuating member **58** is mechanically engaged to the clamp arm assembly **64**, which is pivotable about the pivot point **70**, to open and close the clamp arm assembly **64** in response to the actuation and/or release of the trigger **32**. For example, in the illustrated embodiment, the clamp arm assembly **64** is movable from an open position to a closed position in direction **62**B about a pivot point **70** when the trigger **32** is squeezed in direction **33**A. The clamp arm assembly **64** is movable from a closed position to an open position in direction **62**A about the pivot point **70** when the trigger **32** is released or outwardly contacted in direction **33**B.

As previously discussed, the clamp arm assembly **64** may comprise electrodes electrically coupled to the electrosurgical/RF generator module **23** to receive therapeutic and/or sub-therapeutic energy, where the electrosurgical/RF energy may be applied to the electrodes either simultaneously or non simultaneously with the ultrasonic energy being applied to the blade **66**. Such energy activations may be applied in any suitable combinations to achieve a desired tissue effect in cooperation with an algorithm or other control logic.

FIG. **5** is an exploded view of the ultrasonic surgical instrument **10** shown in FIG. **2**. In the illustrated embodiment, the exploded view shows the internal elements of the handle assembly **12**, the handle assembly **12**, the distal rotation assembly **13**, the switch assembly **28**, and the elongated shaft assembly **14**. In the illustrated embodiment, the first and second portions **12***a*, **12***b* mate to form the handle assembly **12**. The first and second portions **12***a*, **12***b* each comprises a

plurality of interfaces **69** dimensioned to mechanically align and engage one another to form the handle assembly **12** and enclose the internal working components of the ultrasonic surgical instrument **10**. The rotation knob **48** is mechanically engaged to the outer tubular sheath **56** so that it may be rotated in circular direction **54** up to 360°. The outer tubular sheath **56** is located over the reciprocating tubular actuating member **58**, which is mechanically engaged to and retained within the handle assembly **12** via a plurality of coupling elements **72**. The coupling elements **72** may comprise an O-ring **72***a*, a tube collar cap **72***b*, a distal washer **72***c*, a proximal washer **72***d*, and a thread tube collar **72***e*. The reciprocating tubular actuating member **58** is located within a reciprocating yoke **84**, which is retained between the first and second portions **12***a*, **12***b* of the handle assembly **12**. The yoke **84** is part of a reciprocating yoke assembly **88**. A series of linkages translate the pivotal rotation of the elongated trigger hook **32** to the axial movement of the reciprocating yoke **84**, which controls the opening and closing of the jaws of the clamping mechanism of the end effector assembly **26** at the distal end of the ultrasonic surgical instrument **10**. In one example embodiment, a four-link design provides mechanical advantage in a relatively short rotation span, for example.

In one example embodiment, an ultrasonic transmission waveguide **78** is disposed inside the reciprocating tubular actuating member **58**. The distal end **52** of the ultrasonic transmission waveguide **78** is acoustically coupled (e.g., directly or indirectly mechanically coupled) to the blade **66** and the proximal end **50** of the ultrasonic transmission waveguide **78** is received within the handle assembly **12**. The proximal end **50** of the ultrasonic transmission waveguide **78** is adapted to acoustically couple to the distal end of the ultrasonic transducer **16** as discussed in more detail below. The ultrasonic transmission waveguide **78** is isolated from the other elements of the elongated shaft assembly **14** by a protective sheath **80** and a plurality of isolation elements **82**, such as silicone rings. The outer tubular sheath **56**, the reciprocating tubular actuating member **58**, and the ultrasonic transmission waveguide **78** are mechanically engaged by a pin **74**. The switch assembly **28** comprises the toggle switch **30** and electrical elements **86***a,b* to electrically energize the ultrasonic transducer **16** in accordance with the activation of the first or second projecting knobs **30***a*, **30***b*.

In one example embodiment, the outer tubular sheath **56** isolates the user or the patient from the ultrasonic vibrations of the ultrasonic transmission waveguide **78**. The outer tubular sheath **56** generally includes a hub **76**. The outer tubular sheath **56** is threaded onto the distal end of the handle assembly **12**. The ultrasonic transmission waveguide **78** extends through the opening of the outer tubular sheath **56** and the isolation elements **82** isolate the ultrasonic transmission waveguide **78** from the outer tubular sheath **56**. The outer tubular sheath **56** may be attached to the waveguide **78** with the pin **74**. The hole to receive the pin **74** in the waveguide **78** may occur nominally at a displacement node. The waveguide **78** may screw or snap into the hand piece handle assembly **12** by a stud. Flat portions on the hub **76** may allow the assembly to be torqued to a required level. In one example embodiment, the hub **76** portion of the outer tubular sheath **56** is preferably constructed from plastic and the tubular elongated portion of the outer tubular sheath **56** is fabricated from stainless steel. Alternatively, the ultrasonic transmission waveguide **78** may comprise polymeric material surrounding it to isolate it from outside contact.

In one example embodiment, the distal end of the ultrasonic transmission waveguide **78** may be coupled to the proximal end of the blade **66** by an internal threaded connection, preferably at or near an antinode. It is contemplated that the blade **66** may be attached to the ultrasonic transmission waveguide **78** by any suitable means, such as a welded joint or the like. Although the blade **66** may be detachable from the ultrasonic transmission waveguide **78**, it is also contemplated that the single element end effector (e.g., the blade **66**) and the ultrasonic transmission waveguide **78** may be formed as a single unitary piece.

In one example embodiment, the trigger **32** is coupled to a linkage mechanism to translate the rotational motion of the trigger **32** in directions **33**A and **33**B to the linear motion of the reciprocating tubular actuating member **58** in corresponding directions **60**A and **60**B. The trigger **32** comprises a first set of flanges **97** with openings formed therein to receive a first yoke pin **94***a*. The first yoke pin **94***a* is also located through a set of openings formed at the distal end of the yoke **84**. The trigger **32** also comprises a second set of flanges **96** to receive a first end **92***a* of a link **92**. A trigger pin **90** is received in openings formed in the link **92** and the second set of flanges **96**. The trigger pin **90** is received in the openings formed in the link **92** and the second set of flanges **96** and is adapted to couple to the first and second portions **12***a*, **12***b* of the handle assembly **12** to form a trigger pivot point for the trigger **32**. A second end **92***b* of the link **92** is received in a slot **93** formed in a proximal end of the yoke **84** and is retained therein by a second yoke pin **94***b*. As the trigger **32** is pivotally rotated about the pivot point **190** formed by the trigger pin **90**, the yoke translates horizontally along longitudinal axis "T" in a direction indicated by arrows **60**A,B.

FIG. **8** illustrates one example embodiment of an ultrasonic surgical instrument **10**. In the illustrated embodiment, a cross-sectional view of the ultrasonic transducer **16** is shown within a partial cutaway view of the handle assembly **12**. One example embodiment of the ultrasonic surgical instrument **10** comprises the ultrasonic signal generator **20** coupled to the ultrasonic transducer **16**, comprising a hand piece housing **99**, and an ultrasonically actuatable single or multiple element end effector assembly **26**. As previously discussed, the end effector assembly **26** comprises the ultrasonically actuatable blade **66** and the clamp arm **64**. The ultrasonic transducer **16**, which is known as a "Langevin stack", generally includes a transduction portion **100**, a first resonator portion or end-bell **102**, and a second resonator portion or fore-bell **104**, and ancillary components. The total construction of these components is a resonator. The ultrasonic transducer **16** is preferably an integral number of one-half system wavelengths ($n\lambda/2$; where "n" is any positive integer; e.g., n=1, 2, 3 . . . ) in length as will be described in more detail later. An acoustic assembly **106** includes the ultrasonic transducer **16**, a nose cone **108**, a velocity transformer **118**, and a surface **110**.

In one example embodiment, the distal end of the end-bell **102** is connected to the proximal end of the transduction portion **100**, and the proximal end of the fore-bell **104** is connected to the distal end of the transduction portion **100**. The fore-bell **104** and the end-bell **102** have a length determined by a number of variables, including the thickness of the transduction portion **100**, the density and modulus of elasticity of the material used to manufacture the end-bell **102** and the fore-bell **22**, and the resonant frequency of the ultrasonic transducer **16**. The fore-bell **104** may be tapered inwardly from its proximal end to its distal end to amplify the ultrasonic vibration amplitude as the velocity transformer **118**, or alternately may have no amplification. A suitable vibrational frequency range may be about 20 Hz to 32 kHz and a well-suited vibrational frequency range may be about 30-10 kHz. A suitable operational vibrational frequency may be approximately 55.5 kHz, for example.

In one example embodiment, the piezoelectric elements **112** may be fabricated from any suitable material, such as, for example, lead zirconate-titanate, lead meta-niobate, lead titanate, barium titanate, or other piezoelectric ceramic material. Each of positive electrodes **114**, negative electrodes **116**, and the piezoelectric elements **112** has a bore extending through the center. The positive and negative electrodes **114** and **116** are electrically coupled to wires **120** and **122**, respectively. The wires **120** and **122** are encased within the cable **22** and electrically connectable to the ultrasonic signal generator **20**.

The ultrasonic transducer **16** of the acoustic assembly **106** converts the electrical signal from the ultrasonic signal generator **20** into mechanical energy that results in primarily a standing acoustic wave of longitudinal vibratory motion of the ultrasonic transducer **16** and the blade **66** portion of the end effector assembly **26** at ultrasonic frequencies. In another embodiment, the vibratory motion of the ultrasonic transducer may act in a different direction. For example, the vibratory motion may comprise a local longitudinal component of a more complicated motion of the tip of the elongated shaft assembly **14**. A suitable generator is available as model number GEN11, from Ethicon Endo-Surgery, Inc., Cincinnati, Ohio. When the acoustic assembly **106** is energized, a vibratory motion standing wave is generated through the acoustic assembly **106**. The ultrasonic surgical instrument **10** is designed to operate at a resonance such that an acoustic standing wave pattern of predetermined amplitude is produced. The amplitude of the vibratory motion at any point along the acoustic assembly **106** depends upon the location along the acoustic assembly **106** at which the vibratory motion is measured. A minimum or zero crossing in the vibratory motion standing wave is generally referred to as a node (i.e., where motion is minimal), and a local absolute value maximum or peak in the standing wave is generally referred to as an anti-node (e.g., where local motion is maximal). The distance between an anti-node and its nearest node is one-quarter wavelength ($\lambda/4$).

The wires **120** and **122** transmit an electrical signal from the ultrasonic signal generator **20** to the positive electrodes **114** and the negative electrodes **116**. The piezoelectric elements **112** are energized by the electrical signal supplied from the ultrasonic signal generator **20** in response to an actuator **224**, such as a foot switch, for example, to produce an acoustic standing wave in the acoustic assembly **106**. The electrical signal causes disturbances in the piezoelectric elements **112** in the form of repeated small displacements resulting in large alternating compression and tension forces within the material. The repeated small displacements cause the piezoelectric elements **112** to expand and contract in a continuous manner along the axis of the voltage gradient, producing longitudinal waves of ultrasonic energy. The ultrasonic energy is transmitted through the acoustic assembly **106** to the blade **66** portion of the end effector assembly **26** via a transmission component or an ultrasonic transmission waveguide portion **78** of the elongated shaft assembly **14**.

In one example embodiment, in order for the acoustic assembly **106** to deliver energy to the blade **66** portion of the end effector assembly **26**, all components of the acoustic assembly **106** must be acoustically coupled to the blade **66**. The distal end of the ultrasonic transducer **16** may be acoustically coupled at the surface **110** to the proximal end of the ultrasonic transmission waveguide **78** by a threaded connection such as a stud **124**.

In one example embodiment, the components of the acoustic assembly **106** are preferably acoustically tuned such that the length of any assembly is an integral number of one-half wavelengths ($n\lambda/2$), where the wavelength $\lambda$ is the wavelength of a pre-selected or operating longitudinal vibration drive frequency $f_d$ of the acoustic assembly **106**. It is also contemplated that the acoustic assembly **106** may incorporate any suitable arrangement of acoustic elements.

In one example embodiment, the blade **66** may have a length substantially equal to an integral multiple of one-half system wavelengths ($n\lambda/2$). A distal end of the blade **66** may be disposed near an antinode in order to provide the maximum longitudinal excursion of the distal end. When the transducer assembly is energized, the distal end of the blade **66** may be configured to move in the range of, for example, approximately 10 to 500 microns peak-to-peak, and preferably in the range of about 30 to 64 microns at a predetermined vibrational frequency of 55 kHz, for example.

In one example embodiment, the blade **66** may be coupled to the ultrasonic transmission waveguide **78**. The blade **66** and the ultrasonic transmission waveguide **78** as illustrated are formed as a single unit construction from a material suitable for transmission of ultrasonic energy. Examples of such materials include Ti6Al4V (an alloy of Titanium including Aluminum and Vanadium), Aluminum, Stainless Steel, or other suitable materials. Alternately, the blade **66** may be separable (and of differing composition) from the ultrasonic transmission waveguide **78**, and coupled by, for example, a stud, weld, glue, quick connect, or other suitable known methods. The length of the ultrasonic transmission waveguide **78** may be substantially equal to an integral number of one-half wavelengths ($n\lambda/2$), for example. The ultrasonic transmission waveguide **78** may be preferably fabricated from a solid core shaft constructed out of material suitable to propagate ultrasonic energy efficiently, such as the titanium alloy discussed above (i.e., Ti6Al4V) or any suitable aluminum alloy, or other alloys, for example.

In one example embodiment, the ultrasonic transmission waveguide **78** comprises a longitudinally projecting attachment post at a proximal end to couple to the surface **110** of the ultrasonic transmission waveguide **78** by a threaded connection such as the stud **124**. The ultrasonic transmission waveguide **78** may include a plurality of stabilizing silicone rings or compliant supports **82** (FIG. **5**) positioned at a plurality of nodes. The silicone rings **82** dampen undesirable vibration and isolate the ultrasonic energy from an outer protective sheath **80** (FIG. **5**) assuring the flow of ultrasonic energy in a longitudinal direction to the distal end of the blade **66** with maximum efficiency.

FIG. **9** illustrates one example embodiment of the proximal rotation assembly **128**. In the illustrated embodiment, the proximal rotation assembly **128** comprises the proximal rotation knob **134** inserted over the cylindrical hub **135**. The proximal rotation knob **134** comprises a plurality of radial projections **138** that are received in corresponding slots **130** formed on a proximal end of the cylindrical hub **135**. The proximal rotation knob **134** defines an opening **142** to receive the distal end of the ultrasonic transducer **16**. The radial projections **138** are formed of a soft polymeric material and define a diameter that is undersized relative to the outside diameter of the ultrasonic transducer **16** to create a friction interference fit when the distal end of the ultrasonic transducer **16**. The polymeric radial projections **138** protrude radially into the opening **142** to form "gripper" ribs that firmly grip the exterior housing of the ultrasonic transducer **16**. Therefore, the proximal rotation knob **134** securely grips the ultrasonic transducer **16**.

The distal end of the cylindrical hub **135** comprises a circumferential lip **132** and a circumferential bearing surface **140**. The circumferential lip engages a groove formed in the

housing **12** and the circumferential bearing surface **140** engages the housing **12**. Thus, the cylindrical hub **135** is mechanically retained within the two housing portions (not shown) of the housing **12**. The circumferential lip **132** of the cylindrical hub **135** is located or "trapped" between the first and second housing portions **12***a*, **12***b* and is free to rotate in place within the groove. The circumferential bearing surface **140** bears against interior portions of the housing to assist proper rotation. Thus, the cylindrical hub **135** is free to rotate in place within the housing. The user engages the flutes **136** formed on the proximal rotation knob **134** with either the finger or the thumb to rotate the cylindrical hub **135** within the housing **12**.

In one example embodiment, the cylindrical hub **135** may be formed of a durable plastic such as polycarbonate. In one example embodiment, the cylindrical hub **135** may be formed of a siliconized polycarbonate material. In one example embodiment, the proximal rotation knob **134** may be formed of pliable, resilient, flexible polymeric materials including Versaflex® TPE alloys made by GLS Corporation, for example. The proximal rotation knob **134** may be formed of elastomeric materials, thermoplastic rubber known as Santoprene®, other thermoplastic vulcanizates (TPVs), or elastomers, for example. The embodiments, however, are not limited in this context.

FIG. **10** illustrates one example embodiment of a surgical system **200** including a surgical instrument **210** having single element end effector **278**. The system **200** may include a transducer assembly **216** coupled to the end effector **278** and a sheath **256** positioned around the proximal portions of the end effector **278** as shown. The transducer assembly **216** and end effector **278** may operate in a manner similar to that of the transducer assembly **16** and end effector **18** described above to produce ultrasonic energy that may be transmitted to tissue via blade **226**.

Over the years, a variety of minimally invasive robotic (or "telesurgical") systems have been developed to increase surgical dexterity as well as to permit a surgeon to operate on a patient in an intuitive manner. Robotic surgical systems can be used with many different types of surgical instruments including, for example, ultrasonic instruments, as described herein. Example robotic systems include those manufactured by Intuitive Surgical, Inc., of Sunnyvale, Calif., U.S.A. Such systems, as well as robotic systems from other manufacturers, are disclosed in the following U.S. patents which are each herein incorporated by reference in their respective entirety: U.S. Pat. No. 5,792,135, entitled "Articulated Surgical Instrument For Performing Minimally Invasive Surgery With Enhanced Dexterity and Sensitivity", U.S. Pat. No. 6,231,565, entitled "Robotic Arm DLUs For Performing Surgical Tasks", U.S. Pat. No. 6,783,524, entitled "Robotic Surgical Tool With Ultrasound Cauterizing and Cutting Instrument", U.S. Pat. No. 6,364,888, entitled "Alignment of Master and Slave In a Minimally Invasive Surgical Apparatus", U.S. Pat. No. 7,524,320, entitled "Mechanical Actuator Interface System For Robotic Surgical Tools", U.S. Pat. No. 7,691,098, entitled Platform Link Wrist Mechanism", U.S. Pat. No. 7,806,891, entitled "Repositioning and Reorientation of Master/Slave Relationship in Minimally Invasive Telesurgery", and U.S. Pat. No. 7,824,401, entitled "Surgical Tool With Wristed Monopolar Electrosurgical End Effectors". Many of such systems, however, have in the past been unable to generate the magnitude of forces required to effectively cut and fasten tissue.

FIGS. **11-26** illustrate example embodiments of robotic surgical systems. In some embodiments, the disclosed robotic surgical systems may utilize the ultrasonic or electrosurgical instruments described herein. Those skilled in the art will appreciate that the illustrated robotic surgical systems are not limited to only those instruments described herein, and may utilize any compatible surgical instruments. Those skilled in the art will further appreciate that while various embodiments described herein may be used with the described robotic surgical systems, the disclosure is not so limited, and may be used with any compatible robotic surgical system.

FIGS. **11-16** illustrate the structure and operation of several example robotic surgical systems and components thereof. FIG. **11** shows a block diagram of an example robotic surgical system **500**. The system **500** comprises at least one controller **508** and at least one arm cart **510**. The arm cart **510** may be mechanically coupled to one or more robotic manipulators or arms, indicated by box **512**. Each of the robotic arms **512** may comprise one or more surgical instruments **514** for performing various surgical tasks on a patient **504**. Operation of the arm cart **510**, including the arms **512** and instruments **514** may be directed by a clinician **502** from a controller **508**. In some embodiments, a second controller **508'**, operated by a second clinician **502'** may also direct operation of the arm cart **510** in conjunction with the first clinician **502'**. For example, each of the clinicians **502**, **502'** may control different arms **512** of the cart or, in some cases, complete control of the arm cart **510** may be passed between the clinicians **502**, **502'**. In some embodiments, additional arm carts (not shown) may be utilized on the patient **504**. These additional arm carts may be controlled by one or more of the controllers **508**, **508'**. The arm cart(s) **510** and controllers **508**, **508'** may be in communication with one another via a communications link **516**, which may be any suitable type of wired or wireless communications link carrying any suitable type of signal (e.g., electrical, optical, infrared, etc.) according to any suitable communications protocol. Example implementations of robotic surgical systems, such as the system **500**, are disclosed in U.S. Pat. No. 7,524,320 which has been herein incorporated by reference. Thus, various details of such devices will not be described in detail herein beyond that which may be necessary to understand various embodiments of the claimed device.

FIG. **12** shows one example embodiment of a robotic arm cart **520**. The robotic arm cart **520** is configured to actuate a plurality of surgical instruments or instruments, generally designated as **522** within a work envelope **527**. Various robotic surgery systems and methods employing master controller and robotic arm cart arrangements are disclosed in U.S. Pat. No. 6,132,368, entitled "Multi-Component Telepresence System and Method", the full disclosure of which is incorporated herein by reference. In various forms, the robotic arm cart **520** includes a base **524** from which, in the illustrated embodiment, three surgical instruments **522** are supported. In various forms, the surgical instruments **522** are each supported by a series of manually articulatable linkages, generally referred to as set-up joints **526**, and a robotic manipulator **528**. These structures are herein illustrated with protective covers extending over much of the robotic linkage. These protective covers may be optional, and may be limited in size or entirely eliminated in some embodiments to minimize the inertia that is encountered by the servo mechanisms used to manipulate such devices, to limit the volume of moving components so as to avoid collisions, and to limit the overall weight of the cart **520**. Cart **520** will generally have dimensions suitable for transporting the cart **520** between operating rooms. The cart **520** may be configured to typically fit through standard operating room doors and onto standard hospital elevators. In various forms, the cart **520** would preferably have a weight and include a wheel (or other transpor-

tation) system that allows the cart **520** to be positioned adjacent an operating table by a single attendant.

FIG. **13** shows one example embodiment of the robotic manipulator **528** of the robotic arm cart **520**. In the example shown in FIG. **13**, the robotic manipulators **528** may include a linkage **530** that constrains movement of the surgical instrument **522**. In various embodiments, linkage **530** includes rigid links coupled together by rotational joints in a parallelogram arrangement so that the surgical instrument **522** rotates around a point in space **532**, as more fully described in issued U.S. Pat. No. 5,817,084, the full disclosure of which is herein incorporated by reference. The parallelogram arrangement constrains rotation to pivoting about an axis **534***a*, sometimes called the pitch axis. The links supporting the parallelogram linkage are pivotally mounted to set-up joints **526** (FIG. **12**) so that the surgical instrument **522** further rotates about an axis **534***b*, sometimes called the yaw axis. The pitch and yaw axes **534***a*, **534***b* intersect at the remote center **536**, which is aligned along a shaft **538** of the surgical instrument **522**. The surgical instrument **522** may have further degrees of driven freedom as supported by manipulator **540**, including sliding motion of the surgical instrument **522** along the longitudinal instrument axis "LT-LT". As the surgical instrument **522** slides along the instrument axis LT-LT relative to manipulator **540** (arrow **534***c*), remote center **536** remains fixed relative to base **542** of manipulator **540**. Hence, the entire manipulator **540** is generally moved to re-position remote center **536**. Linkage **530** of manipulator **540** is driven by a series of motors **544**. These motors **544** actively move linkage **530** in response to commands from a processor of a control system. As will be discussed in further detail below, motors **544** are also employed to manipulate the surgical instrument **522**.

FIG. **14** shows one example embodiment of a robotic arm cart **520'** having an alternative set-up joint structure. In this example embodiment, a surgical instrument **522** is supported by an alternative manipulator structure **528'** between two tissue manipulation instruments. Those of ordinary skill in the art will appreciate that various embodiments of the claimed device may incorporate a wide variety of alternative robotic structures, including those described in U.S. Pat. No. 5,878,193, the full disclosure of which is incorporated herein by reference. Additionally, while the data communication between a robotic component and the processor of the robotic surgical system is primarily described herein with reference to communication between the surgical instrument **522** and the controller, it should be understood that similar communication may take place between circuitry of a manipulator, a set-up joint, an endoscope or other image capture device, or the like, and the processor of the robotic surgical system for component compatibility verification, component-type identification, component calibration (such as off-set or the like) communication, confirmation of coupling of the component to the robotic surgical system, or the like.

FIG. **15** shows one example embodiment of a controller **518** that may be used in conjunction with a robotic arm cart, such as the robotic arm carts **520**, **520'** depicted in FIGS. **12-14**. The controller **518** generally includes master controllers (generally represented as **519** in FIG. **15**) which are grasped by the clinician and manipulated in space while the clinician views the procedure via a stereo display **521**. A surgeon feed back meter **515** may be viewed via the display **521** and provide the surgeon with a visual indication of the amount of force being applied to the cutting instrument or dynamic clamping member. The master controllers **519** generally comprise manual input devices which preferably move with multiple degrees of freedom, and which often further have a handle or trigger for actuating instruments (for example, for closing grasping saws, applying an electrical potential to an electrode, or the like).

FIG. **16** shows one example embodiment of an ultrasonic surgical instrument **522** adapted for use with a robotic surgical system. For example, the surgical instrument **522** may be coupled to one of the surgical manipulators **528**, **528'** described hereinabove. As can be seen in FIG. **16**, the surgical instrument **522** comprises a surgical end effector **548** that comprises an ultrasonic blade **550** and clamp arm **552**, which may be coupled to an elongated shaft assembly **554** that, in some embodiments, may comprise an articulation joint **556**. FIG. **17** shows one example embodiment of an instrument drive assembly **546** that may be coupled to one of the surgical manipulators **528**, **528'** to receive and control the surgical instrument **522**. The instrument drive assembly **546** may also be operatively coupled to the controller **518** to receive inputs from the clinician for controlling the instrument **522**. For example, actuation (e.g., opening and closing) of the clamp arm **552**, actuation (e.g., opening and closing) of the jaws **551**A, **551**B, actuation of the ultrasonic blade **550**, extension of the knife **555** and actuation of the energy delivery surfaces **553**A, **553**B, etc. may be controlled through the instrument drive assembly **546** based on inputs from the clinician provided through the controller **518**. The surgical instrument **522** is operably coupled to the manipulator by an instrument mounting portion, generally designated as **558**. The surgical instruments **522** further include an interface **560** which mechanically and electrically couples the instrument mounting portion **558** to the manipulator.

FIG. **18** shows another view of the instrument drive assembly of FIG. **17** including the ultrasonic surgical instrument **522**. The instrument mounting portion **558** includes an instrument mounting plate **562** that operably supports a plurality of (four are shown in FIG. **17**) rotatable body portions, driven discs or elements **564**, that each include a pair of pins **566** that extend from a surface of the driven element **564**. One pin **566** is closer to an axis of rotation of each driven elements **564** than the other pin **566** on the same driven element **564**, which helps to ensure positive angular alignment of the driven element **564**. The driven elements **564** and pints **566** may be positioned on an adapter side **567** of the instrument mounting plate **562**.

Interface **560** also includes an adaptor portion **568** that is configured to mountingly engage the mounting plate **562** as will be further discussed below. The adaptor portion **568** may include an array of electrical connecting pins **570**, which may be coupled to a memory structure by a circuit board within the instrument mounting portion **558**. While interface **560** is described herein with reference to mechanical, electrical, and magnetic coupling elements, it should be understood that a wide variety of telemetry modalities might be used, including infrared, inductive coupling, or the like.

FIGS. **19-21** show additional views of the adapter portion **568** of the instrument drive assembly **546** of FIG. **17**. The adapter portion **568** generally includes an instrument side **572** and a holder side **574** (FIG. **19**). In various embodiments, a plurality of rotatable bodies **576** are mounted to a floating plate **578** which has a limited range of movement relative to the surrounding adaptor structure normal to the major surfaces of the adaptor **568**. Axial movement of the floating plate **578** helps decouple the rotatable bodies **576** from the instrument mounting portion **558** when the levers **580** along the sides of the instrument mounting portion housing **582** are actuated (See FIG. **16**) Other mechanisms/arrangements may be employed for releasably coupling the instrument mounting portion **558** to the adaptor **568**. In at least one form, rotatable bodies **576** are resiliently mounted to floating plate **578** by

resilient radial members which extend into a circumferential indentation about the rotatable bodies **576**. The rotatable bodies **576** can move axially relative to plate **578** by deflection of these resilient structures. When disposed in a first axial position (toward instrument side **572**) the rotatable bodies **576** are free to rotate without angular limitation. However, as the rotatable bodies **576** move axially toward instrument side **572**, tabs **584** (extending radially from the rotatable bodies **576**) laterally engage detents on the floating plates so as to limit angular rotation of the rotatable bodies **576** about their axes. This limited rotation can be used to help drivingly engage the rotatable bodies **576** with drive pins **586** of a corresponding instrument holder portion **588** of the robotic system, as the drive pins **586** will push the rotatable bodies **576** into the limited rotation position until the pins **586** are aligned with (and slide into) openings **590**.

Openings **590** on the instrument side **572** and openings **590** on the holder side **574** of rotatable bodies **576** are configured to accurately align the driven elements **564** (FIGS. **18**, **28**) of the instrument mounting portion **558** with the drive elements **592** of the instrument holder **588**. As described above regarding inner and outer pins **566** of driven elements **564**, the openings **590** are at differing distances from the axis of rotation on their respective rotatable bodies **576** so as to ensure that the alignment is not 33 degrees from its intended position. Additionally, each of the openings **590** may be slightly radially elongated so as to fittingly receive the pins **566** in the circumferential orientation. This allows the pins **566** to slide radially within the openings **590** and accommodate some axial misalignment between the instrument **522** and instrument holder **588**, while minimizing any angular misalignment and backlash between the drive and driven elements. Openings **590** on the instrument side **572** may be offset by about 90 degrees from the openings **590** (shown in broken lines) on the holder side **574**, as can be seen most clearly in FIG. **21**.

Various embodiments may further include an array of electrical connector pins **570** located on holder side **574** of adaptor **568**, and the instrument side **572** of the adaptor **568** may include slots **594** (FIG. **21**) for receiving a pin array (not shown) from the instrument mounting portion **558**. In addition to transmitting electrical signals between the surgical instrument **522**, **523** and the instrument holder **588**, at least some of these electrical connections may be coupled to an adaptor memory device **596** (FIG. **20**) by a circuit board of the adaptor **568**.

A detachable latch arrangement **598** may be employed to releasably affix the adaptor **568** to the instrument holder **588**. As used herein, the term "instrument drive assembly" when used in the context of the robotic system, at least encompasses various embodiments of the adapter **568** and instrument holder **588** and which has been generally designated as **546** in FIG. **17**. For example, as can be seen in FIG. **17**, the instrument holder **588** may include a first latch pin arrangement **600** that is sized to be received in corresponding clevis slots **602** provided in the adaptor **568**. In addition, the instrument holder **588** may further have second latch pins **604** that are sized to be retained in corresponding latch devises **606** in the adaptor **568**. See FIG. **20**. In at least one form, a latch assembly **608** is movably supported on the adapter **568** and is biasable between a first latched position wherein the latch pins **600** are retained within their respective latch clevis **602** and an unlatched position wherein the second latch pins **604** may be into or removed from the latch devises **606**. A spring or springs (not shown) are employed to bias the latch assembly into the latched position. A lip on the instrument side **572** of adaptor **568** may slidably receive laterally extending tabs of instrument mounting housing **582**.

As described the driven elements **564** may be aligned with the drive elements **592** of the instrument holder **588** such that rotational motion of the drive elements **592** causes corresponding rotational motion of the driven elements **564**. The rotation of the drive elements **592** and driven elements **564** may be electronically controlled, for example, via the robotic arm **512**, in response to instructions received from the clinician **502** via a controller **508**. The instrument mounting portion **558** may translate rotation of the driven elements **564** into motion of the surgical instrument **522**, **523**.

FIGS. **22-24** show one example embodiment of the instrument mounting portion **558** showing components for translating motion of the driven elements **564** into motion of the surgical instrument **522**. FIGS. **22-24** show the instrument mounting portion with a shaft **538** having a surgical end effector **610** at a distal end thereof. The end effector **610** may be any suitable type of end effector for performing a surgical task on a patient. For example, the end effector may be configured to provide ultrasonic energy to tissue at a surgical site. The shaft **538** may be rotatably coupled to the instrument mounting portion **558** and secured by a top shaft holder **646** and a bottom shaft holder **648** at a coupler **650** of the shaft **538**.

In one example embodiment, the instrument mounting portion **558** comprises a mechanism for translating rotation of the various driven elements **564** into rotation of the shaft **538**, differential translation of members along the axis of the shaft (e.g., for articulation), and reciprocating translation of one or more members along the axis of the shaft **538** (e.g., for extending and retracting tissue cutting elements such as **555**, overtubes and/or other components). In one example embodiment, the rotatable bodies **612** (e.g., rotatable spools) are coupled to the driven elements **564**. The rotatable bodies **612** may be formed integrally with the driven elements **564**. In some embodiments, the rotatable bodies **612** may be formed separately from the driven elements **564** provided that the rotatable bodies **612** and the driven elements **564** are fixedly coupled such that driving the driven elements **564** causes rotation of the rotatable bodies **612**. Each of the rotatable bodies **612** is coupled to a gear train or gear mechanism to provide shaft articulation and rotation and clamp jaw open/close and knife actuation.

In one example embodiment, the instrument mounting portion **558** comprises a mechanism for causing differential translation of two or more members along the axis of the shaft **538**. In the example provided in FIGS. **22-24**, this motion is used to manipulate articulation joint **556**. In the illustrated embodiment, for example, the instrument mounting portion **558** comprises a rack and pinion gearing mechanism to provide the differential translation and thus the shaft articulation functionality. In one example embodiment, the rack and pinion gearing mechanism comprises a first pinion gear **614** coupled to a rotatable body **612** such that rotation of the corresponding driven element **564** causes the first pinion gear **614** to rotate. A bearing **616** is coupled to the rotatable body **612** and is provided between the driven element **564** and the first pinion gear **614**. The first pinion gear **614** is meshed to a first rack gear **618** to convert the rotational motion of the first pinion gear **614** into linear motion of the first rack gear **618** to control the articulation of the articulation section **556** of the shaft assembly **538** in a left direction **620**L. The first rack gear **618** is attached to a first articulation band **622** (FIG. **22**) such that linear motion of the first rack gear **618** in a distal direction causes the articulation section **556** of the shaft assembly **538** to articulate in the left direction **620**L. A second pinion gear

626 is coupled to another rotatable body 612 such that rotation of the corresponding driven element 564 causes the second pinion gear 626 to rotate. A bearing 616 is coupled to the rotatable body 612 and is provided between the driven element 564 and the second pinion gear 626. The second pinion gear 626 is meshed to a second rack gear 628 to convert the rotational motion of the second pinion gear 626 into linear motion of the second rack gear 628 to control the articulation of the articulation section 556 in a right direction 620R. The second rack gear 628 is attached to a second articulation band 624 (FIG. 23) such that linear motion of the second rack gear 628 in a distal direction causes the articulation section 556 of the shaft assembly 538 to articulate in the right direction 620R. Additional bearings may be provided between the rotatable bodies and the corresponding gears. Any suitable bearings may be provided to support and stabilize the mounting and reduce rotary friction of shaft and gears, for example.

In one example embodiment, the instrument mounting portion 558 further comprises a mechanism for translating rotation of the driven elements 564 into rotational motion about the axis of the shaft 538. For example, the rotational motion may be rotation of the shaft 538 itself. In the illustrated embodiment, a first spiral worm gear 630 coupled to a rotatable body 612 and a second spiral worm gear 632 coupled to the shaft assembly 538. A bearing 616 (FIG. 17) is coupled to a rotatable body 612 and is provided between a driven element 564 and the first spiral worm gear 630. The first spiral worm gear 630 is meshed to the second spiral worm gear 632, which may be coupled to the shaft assembly 538 and/or to another component of the instrument 522, 523 for which longitudinal rotation is desired. Rotation may be caused in a clockwise (CW) and counter-clockwise (CCW) direction based on the rotational direction of the first and second spiral worm gears 630, 632. Accordingly, rotation of the first spiral worm gear 630 about a first axis is converted to rotation of the second spiral worm gear 632 about a second axis, which is orthogonal to the first axis. As shown in FIGS. 22-23, for example, a CW rotation of the second spiral worm gear 632 results in a CW rotation of the shaft assembly 538 in the direction indicated by 634CW. A CCW rotation of the second spiral worm gear 632 results in a CCW rotation of the shaft assembly 538 in the direction indicated by 634CCW. Additional bearings may be provided between the rotatable bodies and the corresponding gears. Any suitable bearings may be provided to support and stabilize the mounting and reduce rotary friction of shaft and gears, for example.

In one example embodiment, the instrument mounting portion 558 comprises a mechanism for generating reciprocating translation of one or more members along the axis of the shaft 538. Such translation may be used, for example to drive a tissue cutting element, such as 555, drive an overtube for closure and/or articulation of the end effector 610, etc. In the illustrated embodiment, for example, a rack and pinion gearing mechanism may provide the reciprocating translation. A first gear 636 is coupled to a rotatable body 612 such that rotation of the corresponding driven element 564 causes the first gear 636 to rotate in a first direction. A second gear 638 is free to rotate about a post 640 formed in the instrument mounting plate 562. The first gear 636 is meshed to the second gear 638 such that the second gear 638 rotates in a direction that is opposite of the first gear 636. In one example embodiment, the second gear 638 is a pinion gear meshed to a rack gear 642, which moves in a liner direction. The rack gear 642 is coupled to a translating block 644, which may translate distally and proximally with the rack gear 642. The translation block 644 may be coupled to any suitable component of the shaft assembly 538 and/or the end effector 610 so as to provide reciprocating longitudinal motion. For example, the translation block 644 may be mechanically coupled to the tissue cutting element 555 of the RF surgical device 523. In some embodiments, the translation block 644 may be coupled to an overtube, or other component of the end effector 610 or shaft 538.

FIGS. 25-27 illustrate an alternate embodiment of the instrument mounting portion 558 showing an alternate example mechanism for translating rotation of the driven elements 564 into rotational motion about the axis of the shaft 538 and an alternate example mechanism for generating reciprocating translation of one or more members along the axis of the shaft 538. Referring now to the alternate rotational mechanism, a first spiral worm gear 652 is coupled to a second spiral worm gear 654, which is coupled to a third spiral worm gear 656. Such an arrangement may be provided for various reasons including maintaining compatibility with existing robotic systems 500 and/or where space may be limited. The first spiral worm gear 652 is coupled to a rotatable body 612. The third spiral worm gear 656 is meshed with a fourth spiral worm gear 658 coupled to the shaft assembly 538. A bearing 760 is coupled to a rotatable body 612 and is provided between a driven element 564 and the first spiral worm gear 738. Another bearing 760 is coupled to a rotatable body 612 and is provided between a driven element 564 and the third spiral worm gear 652. The third spiral worm gear 652 is meshed to the fourth spiral worm gear 658, which may be coupled to the shaft assembly 538 and/or to another component of the instrument 522 for which longitudinal rotation is desired. Rotation may be caused in a CW and a CCW direction based on the rotational direction of the spiral worm gears 656, 658. Accordingly, rotation of the third spiral worm gear 656 about a first axis is converted to rotation of the fourth spiral worm gear 658 about a second axis, which is orthogonal to the first axis. As shown in FIGS. 26 and 27, for example, the fourth spiral worm gear 658 is coupled to the shaft 538, and a CW rotation of the fourth spiral worm gear 658 results in a CW rotation of the shaft assembly 538 in the direction indicated by 634CW. A CCW rotation of the fourth spiral worm gear 658 results in a CCW rotation of the shaft assembly 538 in the direction indicated by 634CCW. Additional bearings may be provided between the rotatable bodies and the corresponding gears. Any suitable bearings may be provided to support and stabilize the mounting and reduce rotary friction of shaft and gears, for example.

Referring now to the alternate example mechanism for generating reciprocating translation of one or more members along the axis of the shaft 538, the instrument mounting portion 558 comprises a rack and pinion gearing mechanism to provide reciprocating translation along the axis of the shaft 538 (e.g., translation of a tissue cutting element 555 of the RF surgical device 523). In one example embodiment, a third pinion gear 660 is coupled to a rotatable body 612 such that rotation of the corresponding driven element 564 causes the third pinion gear 660 to rotate in a first direction. The third pinion gear 660 is meshed to a rack gear 662, which moves in a linear direction. The rack gear 662 is coupled to a translating block 664. The translating block 664 may be coupled to a component of the device 522, 523, such as, for example, the tissue cutting element 555 of the RF surgical device and/or an overtube or other component which is desired to be translated longitudinally.

FIGS. 28-32 illustrate an alternate embodiment of the instrument mounting portion 558 showing another alternate example mechanism for translating rotation of the driven elements 564 into rotational motion about the axis of the shaft 538. In FIGS. 28-32, the shaft 538 is coupled to the remainder

of the mounting portion **558** via a coupler **676** and a bushing **678**. A first gear **666** coupled to a rotatable body **612**, a fixed post **668** comprising first and second openings **672**, first and second rotatable pins **674** coupled to the shaft assembly, and a cable **670** (or rope). The cable is wrapped around the rotatable body **612**. One end of the cable **670** is located through a top opening **672** of the fixed post **668** and fixedly coupled to a top rotatable pin **674**. Another end of the cable **670** is located through a bottom opening **672** of the fixed post **668** and fixedly coupled to a bottom rotating pin **674**. Such an arrangement is provided for various reasons including maintaining compatibility with existing robotic systems **500** and/or where space may be limited. Accordingly, rotation of the rotatable body **612** causes the rotation about the shaft assembly **538** in a CW and a CCW direction based on the rotational direction of the rotatable body **612** (e.g., rotation of the shaft **538** itself). Accordingly, rotation of the rotatable body **612** about a first axis is converted to rotation of the shaft assembly **538** about a second axis, which is orthogonal to the first axis. As shown in FIGS. **28-29**, for example, a CW rotation of the rotatable body **612** results in a CW rotation of the shaft assembly **538** in the direction indicated by **634**CW. A CCW rotation of the rotatable body **612** results in a CCW rotation of the shaft assembly **538** in the direction indicated by **634**CCW. Additional bearings may be provided between the rotatable bodies and the corresponding gears. Any suitable bearings may be provided to support and stabilize the mounting and reduce rotary friction of shaft and gears, for example.

FIGS. **33-36**A illustrate an alternate embodiment of the instrument mounting portion **558** showing an alternate example mechanism for differential translation of members along the axis of the shaft **538** (e.g., for articulation). For example, as illustrated in FIGS. **33-36**A, the instrument mounting portion **558** comprises a double cam mechanism **680** to provide the shaft articulation functionality. In one example embodiment, the double cam mechanism **680** comprises first and second cam portions **680**A, **680**B. First and second follower arms **682**, **684** are pivotally coupled to corresponding pivot spools **686**. As the rotatable body **612** coupled to the double cam mechanism **680** rotates, the first cam portion **680**A acts on the first follower arm **682** and the second cam portion **680**B acts on the second follower arm **684**. As the cam mechanism **680** rotates the follower arms **682**, **684** pivot about the pivot spools **686**. The first follower arm **682** may be attached to a first member that is to be differentially translated (e.g., the first articulation band **622**). The second follower arm **684** is attached to a second member that is to be differentially translated (e.g., the second articulation band **624**). As the top cam portion **680**A acts on the first follower arm **682**, the first and second members are differentially translated. In the example embodiment where the first and second members are the respective articulation bands **622** and **624**, the shaft assembly **538** articulates in a left direction **620**L. As the bottom cam portion **680**B acts of the second follower arm **684**, the shaft assembly **538** articulates in a right direction **620**R. In some example embodiments, two separate bushings **688**, **690** are mounted beneath the respective first and second follower arms **682**, **684** to allow the rotation of the shaft without affecting the articulating positions of the first and second follower arms **682**, **684**. For articulation motion, these bushings reciprocate with the first and second follower arms **682**, **684** without affecting the rotary position of the jaw **902**. FIG. **36**A shows the bushings **688**, **690** and the dual cam assembly **680**, including the first and second cam portions **680**B, **680**B, with the first and second follower arms **682**, **684** removed to provide a more detailed and clearer view.

In various embodiments, the instrument mounting portion **558** may additionally comprise internal energy sources for driving electronics and provided desired ultrasonic and/or RF frequency signals to surgical tools. FIGS. **36**B-**36**C illustrate one embodiment of a tool mounting portion **558'** comprising internal power and energy sources. For example, surgical instruments (e.g., instrument **522**) mounted utilizing the tool mounting portion **558'** need not be wired to an external generator or other power source. Instead, the functionality of the generator **20** described herein may be implemented on board the mounting portion **558**.

As illustrated in FIGS. **36**B-**36**C, the instrument mounting portion **558'** may comprise a distal portion **702**. The distal portion **702** may comprise various mechanisms for coupling rotation of drive elements **592** to end effectors of the various surgical instruments **522**, for example, as described herein above. Proximal of the distal portion **702**, the instrument mounting portion **558'** comprises an internal direct current (DC) energy source and an internal drive and control circuit **704**. In the illustrated embodiment, the energy source comprises a first and second battery **706**, **708**. In other respects, the tool mounting portion **558'** is similar to the various embodiments of the tool mounting portion **558** described herein above. The control circuit **704** may operate in a manner similar to that described above with respect to generator **20**. For example, the control circuit **704** may provide an ultrasonic and/or electrosurgical drive signal in a manner similar to that described above with respect to generator **20**.

FIGS. **37-38** illustrates one embodiment of a distal portion **1000** of a surgical instrument comprising a distally positioned jaw assembly **1003**. The distal portion **1000** also comprises an ultrasonic blade **1014** and a shaft **1004** extending along a longitudinal axis **1002**. A clevis **1006** coupled to a distal portion of the shaft **1004** pivotably receives the jaw assembly **1003**. For example, a wrist member **1008** of the jaw assembly **1003** may be pivotably coupled to the clevis **1006** about a first axis or wrist pivot axis **1018**. Pivoting of the jaw assembly **1003** about the wrist pivot axis **1018** may cause the jaw assembly **1003** to pivot in the directions indicated by arrow **1022**. The wrist member **1008** may be coupled to the clevis **1006** utilizing any suitable pivotable connector or connector assembly. For example, in some embodiments, the wrist member **1008** may be coupled to clevis **1006** with a pin **1011** that may ride within a hole **1013** defined by the clevis **1006**.

First and second jaw members **1010**, **1012** may be pivotably coupled to the wrist member **1008** and configured to pivot about a second axis, or jaw pivot axis **1016**. Pivoting of the jaw members **1010**, **1012** about the jaw pivot axis **1016** may cause the respective jaw members **1010**, **1012** to pivot in the directions indicated by arrow **1020**. The jaw members **1010**, **1012** may be pivotable about the jaw pivot axis **1016** relative to one another and absolutely. For example, the jaw members **1010**, **1012** may pivot relative to one another from open positions, where the jaw members **1010**, **1012** are separated from one another as shown in FIG. **37**, to a closed position where the jaw members **1010**, **1012** are substantially parallel to one another (and optionally in contact with one another). For example, tissue may be grasped between the jaw members **1010**, **1012** when they are at or near the closed position. In some embodiments, one or both of the jaw members **1010**, **1012** is also absolutely pivotably about the jaw pivot axis **1016**. This may allow the general orientation of the jaw assembly **1003** to pivot about the axis **1016** (from left to right in the orientation illustrated in FIG. **37**).

FIG. **39** illustrates a head-on view of one embodiment of the distal portion **1000** of the surgical instrument of FIGS. **37-38**. In FIG. **39**, various control pulleys **1026**, **1028**, **1030**,

1032 are illustrated, along with openings 1031, 1032 in the clevis 1006 for control lines to pass through. Additional details of the various control lines and control pulleys are provided herein below. FIG. 39 also illustrates additional details of the jaw members 1010, 1012. In the embodiment shown in FIG. 39, for example, the jaw members 1010, 1012 define teeth 1024. In some embodiments, the teeth 1024 interlock when the jaw members 1010, 1012 are in a closed position relative to one another. In other embodiments, however, the teeth 1024 do not interlock when the jaw members 1010, 1012 are in a closed position relative to one another.

FIGS. 40-41 illustrate one embodiment of the distal portion 1000 of the surgical instrument of FIGS. 37-38 coupled to an instrument mounting portion 1034 for use with a robotic surgical system, such as the system 500 described herein above. The shaft 1004 may be coupled to the instrument mounting portion 1034. The instrument mounting portion 1034 may contain various mechanisms and interfaces for actuating the ultrasonic blade 1014, articulating the jaw assembly 1003 and, in some embodiments, retracting and extending the ultrasonic blade 1014, for example, as described herein below.

FIGS. 42-44 illustrate one embodiment of the distal portion 1000 of the surgical instrument of FIGS. 37-38 showing additional control mechanisms. Each of the jaw members 1010, 1012 may comprise respective pulleys 1041, 1043 centered on the jaw pivot axis 1016. Rotation of the pulleys 1041, 1043 may cause corresponding pivoting of the respective jaw members 1010, 1012. Rotation of the pulleys 1041, 1043 (and corresponding pivoting of the jaw members 1010, 1012) may be brought about utilizing control lines 1038, 1040, 1048, 1050. For example, control line 1040 may be coupled to and/or wrapped around pulley 1043 such that proximal translation of the control line 1040 causes the jaw member 1012 to pivot about the jaw pivot axis 1016 towards the control line 1040 (e.g., out of the page from the perspective shown in FIGS. 42-43). Pivoting of the jaw member 1012 in the opposition direction (e.g., into the page from the perspective shown in FIGS. 42-43) may be actuated utilizing a control line 1048 also coupled to and/or wrapped around the pulley 1043. Proximal translation of the control line 1048 may cause the jaw member 1012 to pivot towards the control line 1048. When the control line 1048 is coupled to the pulley 1043, it may be coupled at a position substantially opposite the position where the control line 1040 is coupled to the pulley 1043. Also, in some embodiments, control lines 1048, 1040 may be opposite ends of a single cable wrapped around the pulley 1043.

Similarly, control line 1038 may be coupled to and/or wrapped around pulley 1041 such that proximal translation of the control line 1038 causes the jaw member 1010 to pivot about the jaw pivot axis 1016 towards the control line 1038 (e.g., again out of the page from the perspective shown in FIGS. 42-43). Control line 1050 may also be coupled to and/or wrapped around pulley 1041 such that proximal translation of the control line 1050 causes the jaw member 1010 to pivot about the jaw pivot axis towards the control line 1050 (e.g., into the page from the perspective shown in FIGS. 42-43). Control lines 1038, 1050 may be separately coupled to the pulley 1041 or, in some embodiments, may represent separate ends of a single cable or other line wrapped around the pulley 1041. It will be appreciated that as the jaw assembly 1003 pivots about the wrist pivot axis 1018, the orientation of the control lines 1038, 1040, 1048, 1050 relative to the pulleys 1041, 1043 may change.

To prevent the control lines from becoming strained and/or disengaged with the pulleys 1041, 1043, various idler pulleys 1026, 1028, 1036, 1042, 1046, 1044, 1030, 1032 (FIG. 39) may be included to route the control lines 1038, 1040, 1048, 1050 to the shaft 1004. Also, in some embodiments, the control lines are routed to the shaft 1004 via holes in the clevis 1006. FIG. 39 illustrates example holes 1031, 1032 that may be utilized by cables 1048, 1050, respectively.

Pivoting of the wrist member 1008 (and thereby the jaw assembly 1003) may also be actuated utilizing control lines. For example, referring to FIGS. 42 and 44, a control line 1052 is visible coupled to the wrist member 1008 at a position offset from the wrist pivot axis 1018. Proximal translation of the control line 1052 may pull the jaw assembly 1003 away from the ultrasonic blade 1014, for example, up from the perspective shown in FIG. 42 and out of the page from the perspective shown in FIG. 44. A similar control line 1053 may be coupled to a lower portion of the wrist member 1008 such that proximal translation of the control line 1053 causes the jaw assembly 1003 to pivot towards the ultrasonic blade 1014 (e.g., down from the perspective shown in FIG. 42 and into the page from the perspective shown in FIG. 44). The control lines 1052, 1053, in some embodiments, may be ends of a single cable or control line wrapped through and coupled to the wrist member 1008. Also, in some embodiments, the control line 1053 may be omitted. Pivoting of the jaw assembly 1003 towards the ultrasonic blade 1014 may be brought about by distal translation of the control member 1052.

The various control lines 1038, 1040, 1048, 1050, 1052, 1053 may extend proximally through the shaft 1004 where they may be actuated at a handle or an instrument mounting portion of a robotic surgical system, such as the instrument mounting portion 1034 described herein. As described above, differential translation of control line pairs (1038/1050, 1040/1048, 1052, 1053) may cause articulation of the various components of the jaw assembly 1003. Differential translation of control lines may be brought about in any suitable manual and/or automated manner, for example, as described above.

FIG. 45A illustrates one embodiment of the instrument mounting portion 1034 showing an example mechanism for actuating various control lines of the surgical instrument of FIGS. 37-38. The various control lines 1038, 1040, 1048, 1050, 1052, 1053 may extend proximally through the shaft 1004 and enter the instrument mounting portion 1034. The various control lines may be routed by routers 1056 to various spools 1039, 1041, 1043 mounted on the rotatable bodies described above. FIG. 45B illustrates a side view of one embodiment of the routers 1056. For example, the router 1056 shown in FIG. 45B comprises a plurality of grooves 1058 for receiving and routing the various control lines. More or fewer grooves may be included in routers 1056, for example, based on the number of control lines that they are configured to route.

Referring back to FIG. 45A, in some embodiments, control lines 1038 and 1050 may be routed to spool 1039. According to the pictured configuration, clockwise rotation of the spool 1039 causes proximal translation of the control line 1038 and distal translation of the control line 1050. This, as described above, may cause the jaw member 1010 to pivot about the jaw pivot axis 1016 to the left from the perspective of FIG. 44 and out of the page from the perspective of FIGS. 42-43. Counterclockwise rotation of the spool 1039 causes distal translation of the control line 1038 and proximal translation of the control line 1050. This, again as described above, may cause the jaw member 1010 to pivot about the jaw pivot axis 1016 to the right from the perspective of FIG. 44 and into the page from the perspective of FIGS. 42-43. Control lines 1040 and 1048 may be routed to spool 1040. Clockwise and counterclockwise rotation of the spool 1041 may differentially trans-

late control lines **1040** and **1048**, causing the jaw member **1012** to pivot about the jaw pivot axis **1016** similar to the jaw member **1010** described above. The control lines **1052** and **1053** may be similarly coupled to spool **1043** to control pivoting of the jaw assembly **1003** about the wrist pivot axis **1016** upon clockwise and counterclockwise rotation of the spool **1043**.

According to various embodiments, the surgical instrument of FIGS. **37-38** may be implemented with a retractable ultrasonic blade **1014**. For example, the ultrasonic blade **1014** may be retractable in a proximal direction such that it is partially or completely within the shaft **1004** and/or clevis **1006**. This may increase the range of motion of the jaw assembly **1003** about the wrist pivot axis **1018**. FIGS. **46-47** illustrate one embodiment of the distal portion **1000** of the surgical instrument of FIGS. **37-38** with a retractable ultrasonic blade **1014**. Referring now to FIG. **46**, the blade **1014** is shown retracted in the proximal direction indicated by arrow **1060** within the shaft **1004**. As can be seen, this increases the range of motion of the jaw assembly **1003** to pivot about the wrist pivot axis **1018**. For example, as illustrated in FIG. **46**, the jaw assembly **1003** may pivot to and past a location where it would have otherwise contacted the ultrasonic blade **1014**. This may increase the range in which the jaw assembly **1003** is able to grasp tissue. In use, the jaw assembly **1003** may grasp tissue while pivoted to the position shown in FIG. **46**. The jaw assembly **1003** may then be pivoted back to and/or beyond the position shown in FIG. **47** so that the blade **1014** may be extended distally to act on the grasped tissue.

The ultrasonic blade **1014** may be coupled to an ultrasonic waveguide **1058** that may extend proximally through the shaft **1004** to an ultrasonic transducer, such as the transducer **16** described above. In some embodiments, translation of the ultrasonic blade **1014** may be brought about by translation of the blade **1014**, waveguide **1058** and transducer assembly. FIG. **48** illustrates one embodiment of the distal portion **1000** of the surgical instrument of FIGS. **37-38** coupled to an instrument mounting portion **1034** of a robotic surgical system configured to extend and retract the ultrasonic blade **1014**. As illustrated, the waveguide **1058** extends proximally from the ultrasonic blade **1014** through the shaft **1004** to the instrument mounting portion where it is coupled to an ultrasonic transducer assembly **1064** located within the instrument mounting portion **1034**. A rack gear **1062** is coupled to the waveguide **1058** and may be positioned to be engaged by a round gear coupled to one of the rotating bodies **612** of the instrument mounting portion **1034**. For example, FIG. **45** illustrates the rack gear **1062** coupled to a gear **1047**, which is, in turn, coupled to a gear **1045** that rotates with the rotating body **612**. Alternate rotation of the rotating body **612** may cause rotation of the respective gears **1045**, **1047** that may, in turn, cause distal and proximal translation of the rack gear **1062**. As the rack gear **1062** is coupled to the waveguide **1058**, distal and proximal translation of the rack gear **1062** may also cause distal and proximal translation of the waveguide **1058**, blade **1014** and transducer **1064**.

In the embodiment illustrated in FIG. **48**, the transducer **1064** is positioned within the instrument mounting portion **1034**. A flexible/extendible cable **1066** may be coupled the transducer **1064** and ultimately to an external cable **1067**. As the transducer translates distally and proximally with the waveguide **1058** and blade **1014**, the cable **1066** may alternately slacken and tighten so as to maintain its connection to the external cable **1067**. FIG. **49** illustrates an alternate embodiment of the distal portion **1000** of the surgical instrument of FIGS. **37-38** coupled to an instrument mounting portion of a robotic surgical system with an external transducer **1070**. As illustrated, the transducer extends beyond the instrument mounting portion **1034**. FIG. **49** also illustrates the track gear **1062** coupled to the waveguide **1058** that may act (in conjunction with one of the rotatable members **612**) to translate the waveguide **1058**, blade **1014** (not shown in FIG. **49**) and transducer **1070** proximally and distally. FIG. **50** illustrates an additional view of the distal portion **1000** of the surgical instrument of FIGS. **37-38** as illustrated in FIG. **49**.

FIG. **51** illustrates one embodiment of the jaw assembly **1003** comprising a clamp pad **1072**. The clamp pad **1072** may comprise one or more components coupled to at least one face of the wrist member **1008** and/or one of the jaw members **1010**, **1012**. For example, FIG. **51** illustrates a face **1074** of the wrist member **1008** directed towards the ultrasonic blade **1014** and a face **1076** of the jaw member **1012** directed towards the ultrasonic blade **1014**. One or more of these faces may be coupled to a clamp pad **1072**. The clamp pad **1072** may be similar to the clamp arm assembly **64** described herein. For example, the clamp pad **1072** may be configured to be in physical contact with the ultrasonic blade **1014** without substantially affecting the operation of the blade **1014**. In the way, a clinician may utilize the jaw assembly **1003** to clamp tissue to the blade **1014** in a manner similar to that described above with respect to clamp arm assembly **64**.

FIGS. **52-55** illustrate one embodiment of a distal portion **1101** of a surgical instrument comprising a jaw assembly **1100**. The distal portion **1101** may additionally comprise a shaft portion **1110**, a clevis **1102** and an ultrasonic blade **1106**. As described herein above, the ultrasonic blade **1106** may be in mechanical communication with an ultrasonic waveguide (not shown in FIG. **52**) that may extend proximally to a transducer, such as the transducer **16** of FIG. **1**. In some embodiments, the ultrasonic bladed **1106** may be retractable, as described herein above.

The jaw assembly **1100** may comprise a jaw member **1102** and an opposable U-shaped jaw member **1104**. The jaw members **1102**, **1104** may be pivotably coupled to the clevis **1102** that may be, in turn, coupled to a shaft **1110**. The jaw members **1102**, **1104** may be separately pivotable about an axis **1109** in a manner similar to that described above by which the jaw members **1010**, **1012** are separately pivotable about the axis **1016**. For example, the jaw members **1102**, **1104** may be separately pivoted about the axis **1109** to an open position where the jaw members **1102**, **1104** are pivoted away from one another. The jaw members **1102**, **1104** may also be separately pivoted about the axis **1109** to a closed position where the jaw members **1102**, **1104** are near and/or in contact with one another, for example, as shown in FIGS. **53** and **55**. In various embodiments the jaw members **1102**, **1104** may be at either an open or closed position at various angles relative to a longitudinal axis **1002** of the shaft. For example, FIG. **52** shows the jaw members **1102**, **1104** in an open position pivoted away from the longitudinal axis **1002**. FIG. **53** shows the jaw members **1102**, **1104** in a closed position substantially parallel to the ultrasonic blade **1106**. The axis **1109** may be substantially parallel to the longitudinal axis **1002**.

In various embodiments, the jaw members **1102**, **1104** may be utilized to capture tissue and maneuver the captured tissue towards the ultrasonic blade **1106** for cutting and/or coagulation. For example, the U-shaped jaw member **1104** may comprise a pair of times **1104***a*, **1104***b*. The tines **1104***a*, **1104***b* may define an opening **1105** between the times **1104***a*, **1104***b*. The jaw member **1102** and ultrasonic blade **1106** may be aligned with the opening. In this way, the jaw members **1102**, **1104** may be pivoted to an open position with at least the jaw member **1102** away from the longitudinal axis **1002** to capture tissue, such as tissue **1114** shown in FIG. **55**. In some

embodiments, the jaw member **1102** may fit at least into the opening **1105** between the tines **1104***a*, **1104***b*. Accordingly, the jaw member **1102** may push a portion of the tissue **1114** through the opening **1105** where it may contact the ultrasonic blade **1106** for cutting and/or coagulation, as shown in FIG. **55**.

The jaw members **1102**, **1104** may be controlled in any suitable manner. For example, referring to FIG. **56**, a pulley **1116** may be positioned about the axis **1109** and coupled to the jaw member **1104**. A similar pulley **1118** may be positioned about the axis **1109** and coupled to the jaw member **1106**. Cables **1120**, **1122** may be coupled around the respective pulleys **1104**, **1106** in a manner similar to that described herein above with respect to pulleys **1041**, **1043** and cables **1038**, **1040**. Differential movement of the cable **1120** may cause the jaw member **1104** to pivot about the axis **1109**, as described above. Similarly, differential movement of the cable **1120** may cause the jaw member **1104** to pivot about the axis **1109** also as described above. Referring now to FIG. **54**, the shaft **1112** may define a cavity **1115**. The respective cables **1120**, **1122** may extend proximally from the jaw assembly **1100** through the cavity **1115**. The cables **1120**, **1122** may be controlled in any suitable manner. For example, the cables may be controlled by an instrument mounting portion, similar to the instrument mounting portion shown in FIG. **45** and/or by a hand-held controller, such as the handle **12** described herein above.

## Non-Limiting Embodiments

Various embodiments are directed to surgical instruments comprising an end effector, a shaft and a jaw assembly. The end effector may comprise an ultrasonic blade extending distally substantially parallel to a longitudinal axis. The shaft may extend proximally from the end effector along the longitudinal axis. The jaw assembly may comprise first and second jaw members. The jaw assembly may be pivotable about a first axis substantially perpendicular to the longitudinal axis from a first position where the first and second jaw members are substantially parallel to the ultrasonic blade to a second position. Additionally, the first and second jaw members may be pivotable about a second axis substantially perpendicular to the first axis.

In some embodiments, the jaw assembly comprises a wrist member, a first jaw member and a second jaw member. The wrist member may be pivotable about a wrist pivot axis substantially perpendicular to the longitudinal axis from a first position where the wrist member is substantially parallel to the ultrasonic blade to a second position where the wrist member is pivoted away from the ultrasonic blade. The first jaw member may extend distally from and be pivotably coupled to the wrist member. The first jaw member may also be pivotable about a jaw pivot axis substantially perpendicular to the wrist pivot axis. The second jaw member may extend distally from and also be pivotably coupled to the wrist member. The second jaw member may also be pivotable about the jaw pivot axis. The first and second jaw members may be further pivotable about the jaw pivot axis relative to one another from an open position where the first and second jaw members are pivoted away from one another to a closed position where the first and second jaw members are pivoted towards one another.

Applicant also owns the following patent applications that are each incorporated by reference in their respective entireties:

U.S. patent application Ser. No. 13/536,271, filed on Jun. 28, 2012 and entitled "Flexible Drive Member," now U.S. Patent Application Publication No. 2014/0005708;

U.S. patent application Ser. No. 13/536,288, filed on Jun. 28, 2012 and entitled "Multi-Functional Powered Surgical Device with External Dissection Features," now U.S. Patent Application Publication No. 2014/0005718;

U.S. patent application Ser. No. 13/536,295, filed on Jun. 28, 2012 and entitled "Rotary Actuatable Closure Arrangement for Surgical End Effector," now U.S. Patent Application Publication No. 2014/0005676;

U.S. patent application Ser. No. 13/536,326, filed on Jun. 28, 2012 and entitled "Surgical End Effectors Having Angled Tissue-Contacting Surfaces," now U.S. Patent Application Publication No. 2014/0005653;

U.S. patent application Ser. No. 13/536,303, filed on Jun. 28, 2012 and entitled "Interchangeable End Effector Coupling Arrangement," now U.S. Patent Application Publication No. 2014/0005661;

U.S. patent application Ser. No. 13/536,393, filed on Jun. 28, 2012 and entitled "Surgical End Effector Jaw and Electrode Configurations," now U.S. Patent Application Publication No. 2014/0005640;

U.S. patent application Ser. No. 13/536,362, filed on Jun. 28, 2012 and entitled "Multi-Axis Articulating and Rotating Surgical Tools," now U.S. Patent Application Publication No. 2014/0005662; and

U.S. patent application Ser. No. 13/536,417, filed on Jun. 28, 2012 and entitled "Electrode Connections for Rotary Driven Surgical Tools," now U.S. Patent Application Publication No. 2014/0005680.

It will be appreciated that the terms "proximal" and "distal" are used throughout the specification with reference to a clinician manipulating one end of an instrument used to treat a patient. The term "proximal" refers to the portion of the instrument closest to the clinician and the term "distal" refers to the portion located furthest from the clinician. It will further be appreciated that for conciseness and clarity, spatial terms such as "vertical," "horizontal," "up," or "down" may be used herein with respect to the illustrated embodiments. However, surgical instruments may be used in many orientations and positions, and these terms are not intended to be limiting or absolute.

Various embodiments of surgical instruments and robotic surgical systems are described herein. It will be understood by those skilled in the art that the various embodiments described herein may be used with the described surgical instruments and robotic surgical systems. The descriptions are provided for example only, and those skilled in the art will understand that the disclosed embodiments are not limited to only the devices disclosed herein, but may be used with any compatible surgical instrument or robotic surgical system.

Reference throughout the specification to "various embodiments," "some embodiments," "one example embodiment," or "an embodiment" means that a particular feature, structure, or characteristic described in connection with the embodiment is included in at least one example embodiment. Thus, appearances of the phrases "in various embodiments," "in some embodiments," "in one example embodiment," or "in an embodiment" in places throughout the specification are not necessarily all referring to the same embodiment. Furthermore, the particular features, structures, or characteristics illustrated or described in connection with one example embodiment may be combined, in whole or in part, with features, structures, or characteristics of one or more other embodiments without limitation.

While various embodiments herein have been illustrated by description of several embodiments and while the illustrative embodiments have been described in considerable detail, it is not the intention of the applicant to restrict or in any way limit the scope of the appended claims to such detail. Additional advantages and modifications may readily appear to those skilled in the art. For example, each of the disclosed embodiments may be employed in endoscopic procedures, laparoscopic procedures, as well as open procedures, without limitations to its intended use.

It is to be understood that at least some of the figures and descriptions herein have been simplified to illustrate elements that are relevant for a clear understanding of the disclosure, while eliminating, for purposes of clarity, other elements. Those of ordinary skill in the art will recognize, however, that these and other elements may be desirable. However, because such elements are well known in the art, and because they do not facilitate a better understanding of the disclosure, a discussion of such elements is not provided herein.

While several embodiments have been described, it should be apparent, however, that various modifications, alterations and adaptations to those embodiments may occur to persons skilled in the art with the attainment of some or all of the advantages of the disclosure. For example, according to various embodiments, a single component may be replaced by multiple components, and multiple components may be replaced by a single component, to perform a given function or functions. This application is therefore intended to cover all such modifications, alterations and adaptations without departing from the scope and spirit of the disclosure as defined by the appended claims.

Any patent, publication, or other disclosure material, in whole or in part, that is said to be incorporated by reference herein is incorporated herein only to the extent that the incorporated materials does not conflict with existing definitions, statements, or other disclosure material set forth in this disclosure. As such, and to the extent necessary, the disclosure as explicitly set forth herein supersedes any conflicting material incorporated herein by reference. Any material, or portion thereof, that is said to be incorporated by reference herein, but which conflicts with existing definitions, statements, or other disclosure material set forth herein will only be incorporated to the extent that no conflict arises between that incorporated material and the existing disclosure material.

What is claimed is:

**1**. A surgical instrument comprising:

an ultrasonic blade positioned at a distal end of an ultrasonic waveguide, the ultrasonic waveguide extending distally substantially parallel to a longitudinal axis;

a shaft extending proximally from the ultrasonic blade along the longitudinal axis; and

a jaw assembly, wherein the jaw assembly comprises:

a wrist member pivotable about a wrist pivot axis substantially perpendicular to the longitudinal axis from a first position where the wrist member is substantially parallel to the ultrasonic blade to a second position where the wrist member is pivoted away from the ultrasonic blade, wherein the wrist pivot axis is offset from the ultrasonic blade in an offset direction, wherein the offset direction is perpendicular to the longitudinal axis;

a first jaw member extending distally from and pivotably coupled to the wrist member, wherein the first jaw member is pivotable about a jaw pivot axis substantially perpendicular to the wrist pivot axis; and

a second jaw member extending distally from and pivotably coupled to the wrist member, wherein the second jaw member is pivotable about the jaw pivot axis, and wherein the first and second jaw members are further pivotable about the jaw pivot axis relative to one another from an open position where the first and second jaw members are pivoted away from one another to a closed position where the first and second jaw members are pivoted towards one another.

**2**. The instrument of claim **1**, further comprising:

a first jaw control line extending proximally from the first jaw member through the shaft;

a second jaw control line extending proximally from the first jaw member through the shaft, wherein differential translation of the first jaw control line and the second jaw control line causes the first jaw member to pivot about the jaw pivot axis;

a third jaw control line extending proximally from the second jaw member through the shaft; and

a fourth jaw control line extending proximally from the second jaw member through the shaft, wherein differential translation of the third jaw control line and the fourth jaw control line causes the second jaw member to pivot about the jaw pivot axis.

**3**. The instrument of claim **2**, wherein the first jaw member comprises a pulley positioned about the jaw pivot axis and wherein the first jaw control line and the second jaw control line extend around the pulley.

**4**. The instrument of claim **3**, wherein the first and second jaw control lines are ends of a single control line positioned around the pulley.

**5**. The instrument of claim **1**, wherein the first and second jaw members are pivotable about the jaw pivot axis individually and collectively.

**6**. The instrument of claim **1**, further comprising a first wrist member control line coupled to the wrist member and extending proximally through the shaft, wherein proximal translation of the first wrist member control line pivots the wrist member proximally about the wrist pivot axis.

**7**. The instrument of claim **1**, wherein the ultrasonic blade is translatable in a direction parallel to the longitudinal axis from an extended position to a retracted position.

**8**. The instrument of claim **7**, wherein a range of motion of the wrist member about the wrist pivot axis is increased when the ultrasonic blade is in the retracted position.

**9**. The instrument of claim **1**, wherein at least one of the wrist member, the first jaw member, and the second jaw member define a face directed towards the ultrasonic blade, and further comprising a clamp pad material coupled to the face.

**10**. A surgical instrument comprising:

an ultrasonic blade positioned at a distal end of an ultrasonic waveguide, the ultrasonic waveguide extending distally substantially parallel to a longitudinal axis;

a shaft extending proximally from the ultrasonic blade along the longitudinal axis; and

a jaw assembly comprising first and second jaw members, wherein the jaw assembly is pivotable about a first axis substantially perpendicular to the longitudinal axis from a first position where the first and second jaw members are substantially parallel to the ultrasonic blade to a second position, wherein the first and second jaw members are pivotable about a second axis substantially perpendicular to the first axis, and wherein the first axis is offset from the ultrasonic blade in an offset direction, wherein the offset direction is perpendicular to the longitudinal axis.

**11**. The surgical instrument of claim **10**, wherein the first and second jaw members are pivotable relative to each other

about the second axis from a closed position where the first and second jaw members are substantially parallel to each other to an open position.

**12**. The surgical instrument of claim **10**, wherein the jaw assembly further comprises a wrist member pivotable about the first axis, wherein the first and second jaw members are pivotably coupled to the wrist member about the second axis.

**13**. The instrument of claim **10**, further comprising:

a first jaw control line extending proximally from the first jaw member through the shaft;

a second jaw control line extending proximally from the first jaw member through the shaft, wherein differential translation of the first jaw control line and the second jaw control line causes the first jaw member to pivot about the second axis;

a third jaw control line extending proximally from the second jaw member through the shaft; and

a fourth jaw control line extending proximally from the second jaw member through the shaft, wherein differential translation of the third jaw control line and the fourth jaw control line causes the second jaw member to pivot about the second axis.

**14**. The instrument of claim **13**, wherein the first jaw member comprises a pulley positioned about the second axis and wherein the first jaw control line and the second jaw control line extend around the pulley.

**15**. The instrument of claim **10**, wherein the first and second jaw members are pivotable about the second axis individually and together.

**16**. The instrument of claim **10**, further comprising a first axis control line coupled to the jaw assembly and extending proximally through the shaft, wherein proximal translation of the first axis control line pivots the jaw assembly proximally about the first axis.

**17**. The instrument of claim **10**, wherein the ultrasonic blade is translatable in a direction parallel to the longitudinal axis from an extended position to a retracted position.

**18**. The instrument of claim **17**, wherein a range of motion of the jaw assembly about the first axis is increased when the ultrasonic blade is in the retracted position.

**19**. The instrument of claim **10**, wherein the jaw assembly defines a face directed towards the ultrasonic blade, and further comprising a clamp pad material coupled to the face.

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